NASA Contractor Report CR 185216

CONCEPTUAL DEFINITION OF A
HIGH VOLTAGE POWER SUPPLY TEST FACILITY

Final Technical Report

John J. Biess, Teh-Ming Chu and N. John Stevens
TRW Space & Technology Group
Redondo Beach, California

December 1989

Prepared for
Lewis Research Center
Under Contract NAS3-25089

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16. Abstract

NASA Lewis Research Center is presently developing a 60 GHz traveling wave tube for satellite cross-link communications. The operating voltage for this new tube is - 20 kV. There is concern about the high voltage insulation system and NASA is planning a space station high voltage experiment that will demonstrate both the 60 GHz communications and high voltage electronics technology. This study contract determines the experiment interfaces, requirements, conceptual design, technology issues and safety issues.

A block diagram of the high voltage power supply test facility was generated. It includes the high voltage power supply, the 60 GHz traveling wave tube, the communications package, the antenna package, a high voltage diagnostics package and a command and data processor system.

The interfaces with the space station and the attached payload accommodations equipment were determined. A brief description of the different subsystems and a discussion of the technology development needs are presented.

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1.0 Introduction

There is a need for high frequency satellite to satellite crosslink communications in order to increase the data rate. The 60 Gigahertz (GHz) communications link is an excellent candidate. Many new technology developments are required, namely the 60 GHz Traveling Wave Tube (TWT) and its high voltage power supply operating at voltages of minus (-) 20 KV.

This study provides a conceptual design of the 60 GHz crosslink technology demonstration as a space station attached payload experiment. Section 2.0 presents the Space Station Attached Payloads Accommodation Equipment (APAE) description and interfaces for the attached Space Station experiments. Section 3.0 presents the High Voltage Power Supply (HVPS) Test Facility conceptual design. It includes the High Voltage Power Supply (Section 3.1), the 60 GHz Traveling Wave Tube (TWT) (Section 3.2), the Communication Experiment Conceptual definition (Section 3.3), the Diagnostic Package (Section 3.4) and a Command and Data Processor (Section 3.5). Section 4.0 presents a summary of the study conclusions.

2.0 Space Station Attached Payload Accommodation Equipment Interfaces

The high voltage power supply test facility is planned to be mounted on the space station as an attached payload. This section will discuss the different interfaces with the space station and the characteristics of the attached payload accommodations equipment (APAE). The document "Space Station Freedom - WP3 Accommodation Equipment User Handbook" DR-UID02, March 1989, Rev A. prepared by G.E. Astro-Space Division, Valley Forge, PA discusses in detail the different interfaces with an attached payload. This document supplies information for Users of the space station, Freedom, to aid in designing payloads that could be attached to the space station truss and provides background information regarding operations of the space station, Freedom.

The space station is designed to operate at a 28.5 degrees inclination from 150 nmi (276 km) to 270 nmi (500 km) with a nominal operating altitude between 220 and 250 nmi. Pressurized and unpressurized logistics carriers provide supplies and equipment. Limited provisions for payload servicing are available. A Mobile Servicing Center (MSC) and a Flight Telerobotic Servicer (FTS) will be used to assist in the assembly of payloads and payload equipment and for a number of servicing tasks.

The space station will provide payload support subsystems including data management, power, thermal control, communications and tracking, guidance, navigation and control, environmental control, human life support and fluid management.

The central truss of the space station has provisions for the attachment of payloads along its length on the top (zenith), bottom (nadir), and back (anti-velocity) faces between the two alpha rotating joints shown in Figure 2-1. The front face is used for the MSC or FTS. Utilities provided include power, thermal control, structure support, pointing, command and control, video and data handling. As an option APAE can also provide pointing to compensate for the space station motion or to seek specific targets and attitude determination for payloads that require knowledge to an accuracy better than that provides by the space station.

2.1 Attached Payload Accommodations Equipment (APAE)

The APAE provides the accommodations for the external User payloads attached to the central truss of the space station. The APAE provides all the hardware and software interfaces required for the installation, checkout, operation, maintenance, repair and removal of payloads attached to the central truss.

The APAE is capable of accommodating large and moderately sized payloads and groups of small payloads. Space Station Freedom services to be provided to the payloads include:

- o Launch to orbit and return to ground
- o Transport, installation and removal on the space station of attached payloads
- o Power, thermal, data, command and video resources
- o Normal payload operation, in some cases servicing and repair
- o Maintenance and repair.

All interfaces between an attached payload and the space station will be through the APAE. The main mechanical (structure) interface component of the APAE are the space station interface adapter (SIA), the Payload Interface Adapter (PIA), the Deck Carrier and if required , the Payload Pointing System (PPS). Typical implementations of payload attachments are shown in Figure 2-2. The SIA provides standard mounting and resource interface to the space station central truss, while the PIA extends the resource interfaces to the payload. The Deck Carrier is capable of providing structural support for a payload that must be accommodated with in the cargo bay of the Space Shuttle, but does not span the Shuttle attach points. The PPS is a three axis gimbal to which a payload can be mounted.

The APAE will be used to mount and operate external scientific payloads. The APAE will include a structural interface between the space station and the payloads and the distributed systems outlets to supply the payloads with power, thermal control and command and data links. The APAE will be designed to accommodate a variety of external payloads from pre-integrated instrument pallets to single instruments requiring gimbaled pointing.

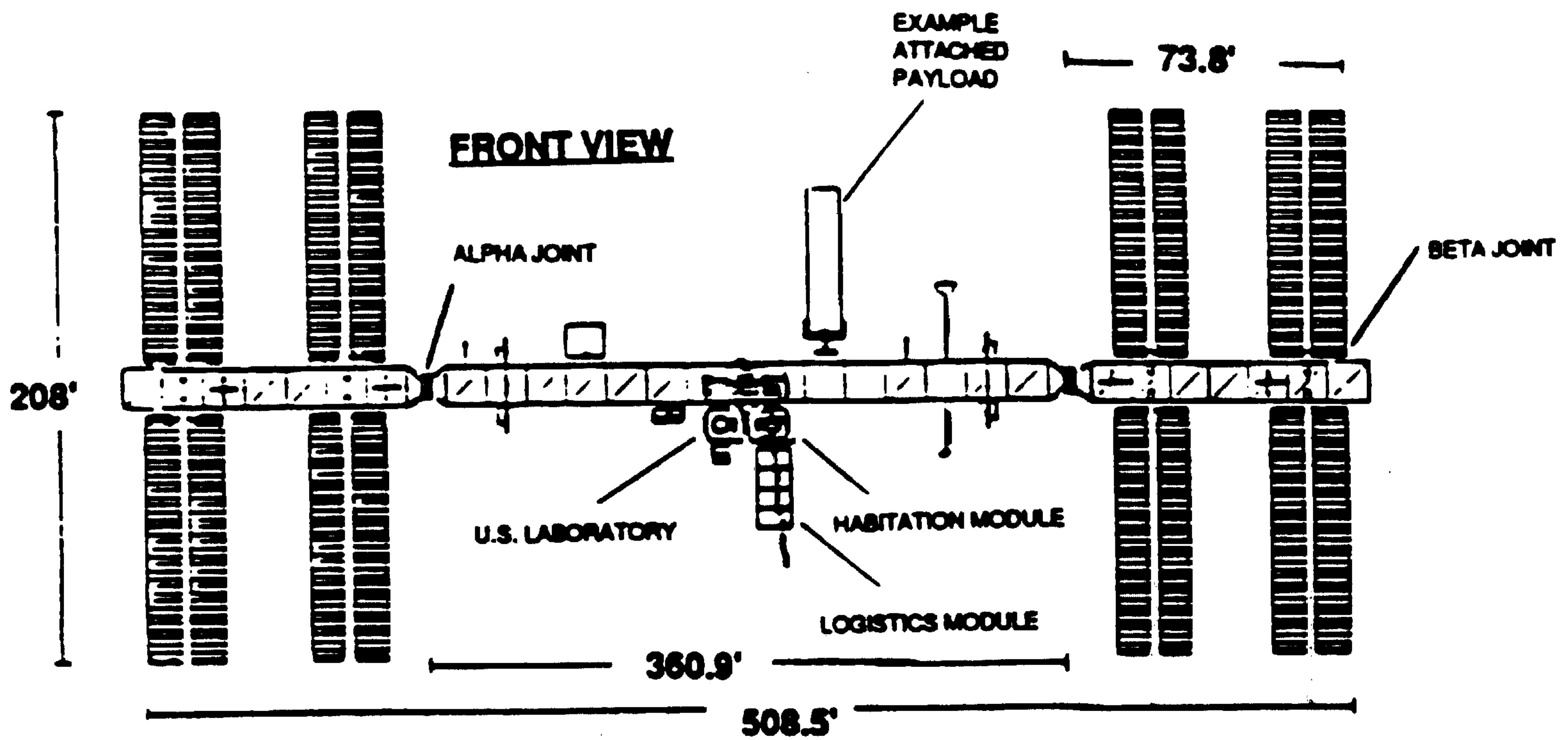

Figure 2-1. Space Station Baseline Configuration - Forward View

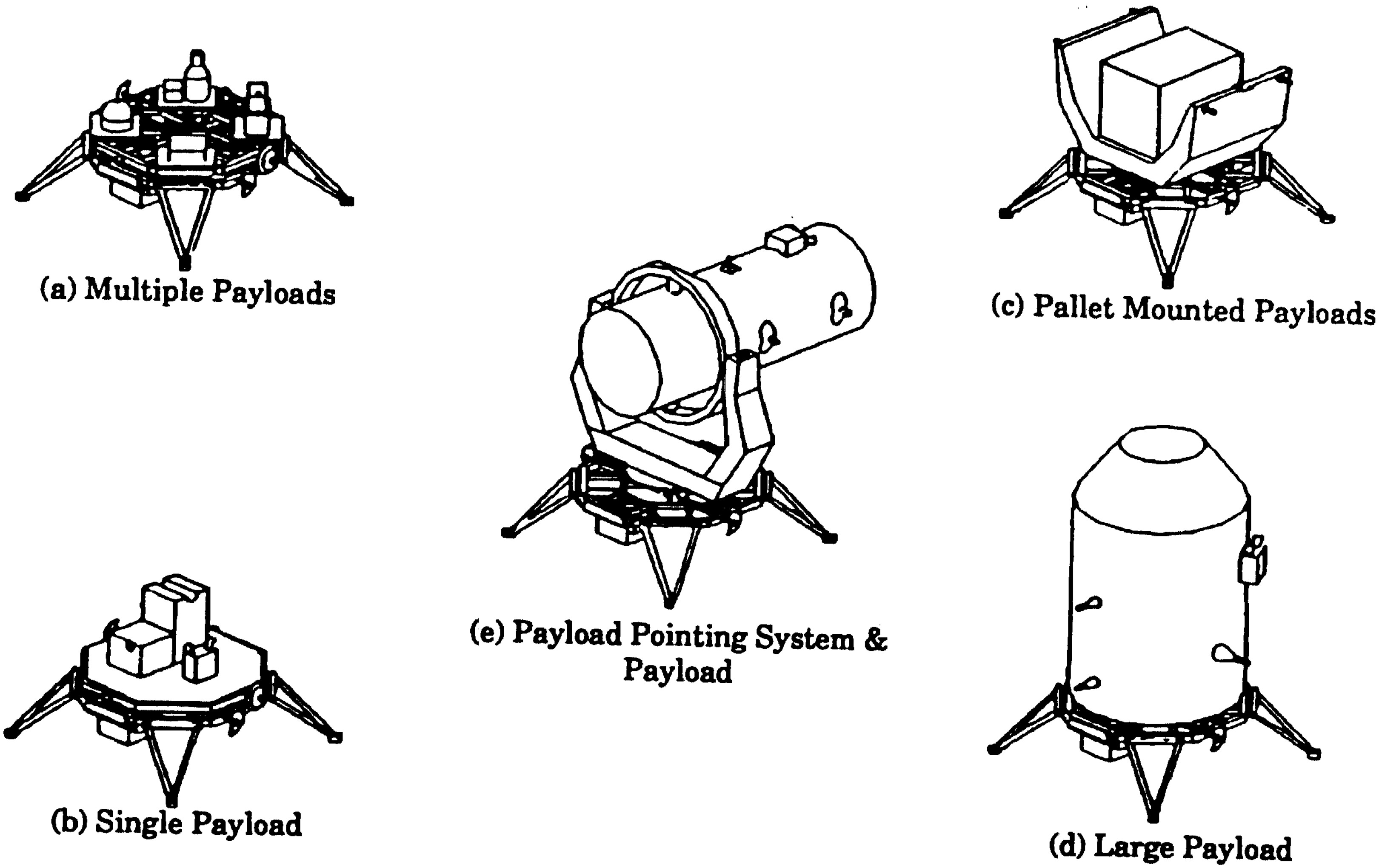

Figure 2-2. Typical Attached Payload Accommodations

2.1.1 Electrical Power System (EPS)

The space station EPS provides all users and housekeeping electrical power and all auxiliary power systems required by the space station. Contingency power will be provided to enable the space station to return to normal operation at the end of one orbit without solar input. Power down to minimum safe levels will be utilized to minimize the impact on the EPS.

The EPS will generate and distribute an average of 37.5 kilowatts of electrical power to the space station housekeeping functions and Users. The EPS provides 120 Vdc power to the User interface. This standard power will be used by all U.S. and International partners including manned base modules, attached payloads and other equipment. Converters will be available to provide 28 Vdc loads and 120/208 Vac, 60 Hz loads.

The overall distribution subsystem will be composed of equipment necessary to process, control and distribute to other space station subsystems, elements and attached payloads. The distribution equipment will include cables, load converters, transformers, regulators, switched and other standard electrical equipment.

Grounding will be at a single point. All equipment operating from a common, isolated power source will be commonly bonded such that fault currents will be limited for safety. Redundant equipment power sources will share a common single point ground. All grounding shall conform to SSP 30240 SSFMB Grounding Standard. All wiring will be short circuit protected with replaceable or resettable devices or be current limited.

2.1.2 Thermal Control System (TCS)

The TCS will control the temperature and heat distribution throughout the space station and reject the heat produced by onboard systems. The TCS is composed of a Passive Thermal Control System (PTCS) and an Active Thermal Control System (ATCS). The PTCS utilizes conventional control techniques such as radiators and blankets. The ATCS is a two phase ammonia system for external portions of the space station. Waste heat acquisition, transport and rejection will be provided for each attached payload to permit thermal control for a wide range of payloads. An integrated thermal utility bus will collect and transport waste heat from the attached payloads to central thermal bus radiators. The ATCS consists of four independent loops. There will be primary and redundant loops at 70 degrees F (21 degrees C) and primary and redundant loops at 35 degrees F (2 degrees C). The temperature of the 70 degrees F loops can be adjusted so that they can run at 35 degrees F in the event of a malfunction of the lower temperature loops. These four loops will interface with a modularized, erectable central heat pipe radiator system. This radiator assembly, located on the central truss, will include a rotary fluid joint that permits the radiator to be rotated away from the radiant heat of the sun.

For truss attached payloads, thermal acquisition is provided at the payload attachment interface. Separate APAE thermal loops will transport waste heat to the central thermal bus heat exchangers.

2.1.3 Space Station Information System (SSIS)

Information processing and communications capabilities will be with a network of related systems, collectively called the space station information system (SSIS). Using the on-board Data Management System (DMS) and the Communications and Tracking (C&T), the SSIS will provide information flow within the space station for housekeeping and User purposes, and to and from Earth.

The SSIS will be transparent to both the Users and operators of the space station. The User on Earth will in effect have a direct link to the space station even though his data will be switched through a complex network. Standard formats and database managers will permit the User to share operational databases and transport software throughout the SSIS.

2.1.3.1 Data Management System (DMS)

The DMS will be an on-board computer system to provide the hardware and software resources necessary to support the data processing and control needs of Space Station Freedom systems, elements and payloads. The DMS will also provide a standardized, homogeneous operating environment and human-machine interfaces for both the crew and ground operators.

The DMS provides database access, command and control, data transmission, data processing and handling and man-machine interfaces for the Users and subsystems and interfaces for international element on-board information systems. Users and subsystems will be able to initiate on-line capabilities such as command generation, data handling, graphics, health monitoring, planning, scheduling and training activities, display of performance and trend data and monitoring of properly interfaced payloads. The information and data management services provided include: data storage; processing and handling;presentation; and on-board networking services adequate to accommodate most User requirements.

The DMS will support transmission of data with User selectable error performance commensurate with the type of data being transmitted. The DMS will provide for storage and activation of stored command sequences. Real time command and control can be initiated by the system, ground operators or the crew. The DMS will be able to route 32 Mbps of data between attached payloads and the laboratory modules for Users.

2.1.3.2 Communications and Tracking (C&T)

C&T will provide all the communications services necessary to support space station and payload operations. These will include command and control, audio, high rate data and telemetry and communication and tracking services both space-to-space and space-to-ground.

The space-to-space subsystem will provide communication with astronauts performing EVA, with the Space Shuttle, the OMV, the MSC, the FTS and any compatible free-flying platforms in the vicinity of the space station. The space-to-ground subsystem will provide communication via satellites to the ground data networks and provides the data buffering required during communications loss-of-signal, satellite link unavailability or link bandwidth limitations.

Primary communications between ground, space station and platforms will be through TDRSS. Operating frequencies, data rates, modulation and encoding will conform to the TDRSS Users' Guide, STDN 101.2 Rev. 5 (or latest approved version). Data Rates in excess of the maximum space station capability may be transmitted as individual data streams to the ground using payload provided systems, subject to the space station system environmental and resource constraints.

2.2 Environments

Experiment and associated support/accommodation equipment will have to withstand the same natural and induced environments as other space station systems and equipment items. Specifications for these environments are still being developed. The latest status is defined in SSFP document 30000, Section 3, Appendix A. Natural environments include: the natural atmosphere as defined by the MSFC/J70 Model, plasma, penetrating charged particles, electromagnetic radiation, meteorites and space debris, the earth's magnetic field, Sun-Earth thermal radiation and pressure parameters, and the earth's gravitational field. Induced environments include: ground handling and transportation; vibration, contamination; and electromagnetic interference caused by space station systems and other experiments. (See SSP 30249 - Space Station Electromagnetic, Ionizing Radiation and Plasma Environment Definition and Design Requirements for induced environments.)

2.3 Contamination Monitoring System (CMS)

The CMS for the APAE monitors and measures contamination levels at or near attached payload locations and provides a status and warning system to alert Users of changes in contamination that could degrade equipment, effect data accuracy and/or require changes in operational procedures. In addition to providing status data for display at Crew Support Station or on the ground, the CMS will have the capability to provide data to the Payload Attachment System (PAS) controller Multiplexer/Demultiplexer (CMDM), so that PAS CMDM can warn and initiate protective measures by the attached payloads. Threshold levels for the PAS CMDM will be set through negotiations between the Users and the space station.

Standard contamination monitoring capabilities of the CMS will include total pressure, molecular species, molecular deposition, and particulate deposition. The current CMS measurement sensitivities are :

total pressure	2E-10 to 2E-3 Torr
Molecular species	8E-11 to 8E-4 Torr and 1 to 150 AMU
Molecular deposition	4.4E-9 grams/square cm
Particulate deposition	3.5E-9 grams/square cm

In the current design, measurements are performed by detecting substances at/or through the measurement unit itself. Thus, the mounting location is critical. No field-of-view measurements,spectral irradiance or molecular column density measurements are possible.

2.4 Grapple Fixture

A power and data grapple fixture, similar to those used in the Shuttle cargo bay for removing and installing payloads, provides the primary structural interface between the APAE/payload structure and the MSC and the FTS. The grapple fixture can have the capability of providing limited power and data for: survival heaters during transportation; mechanism activation; monitoring critical functions for a limited time; and similar applications.

2.5 Mobile Servicing Center (MSC)

The MSC shown in Figure 2-3 is an automated facility used for assembling, routine servicing and maintaining the space station and attached payloads. The Mobile Remote Servicer (MRS), provided by Canada and the Mobile Transporter (MT), provides by the U.S. will make up the MSC. The MT will ride alone rails mounted on the front face of the central truss, providing mobility for the MSC. The MSC will able to remove cargo such as attached payloads and APAE from the Shuttle cargo bay, transport that cargo to the point of assembly or storage, support EVA assembly functions with crew positioning devices, and provide post-assembly inspection.

2.6 Flight Telerobotic Servicer (FTS)

The FTS will be a highly automated telerobotic device capable of precise manipulations including routine and hazardous tasks. The FTS will be used to reduce EVA time and risk. Proposed initial functions include: installing truss members; installing fixtures such as the SIA on the central truss; changing out of ORUs; mating the thermal utility connectors; and performing inspection tasks.

Astronauts will operate/monitor the FTS during either direct manipulator control or programmed command sequences. The FTS is designed to be operated from several different workstations as the space station develops.

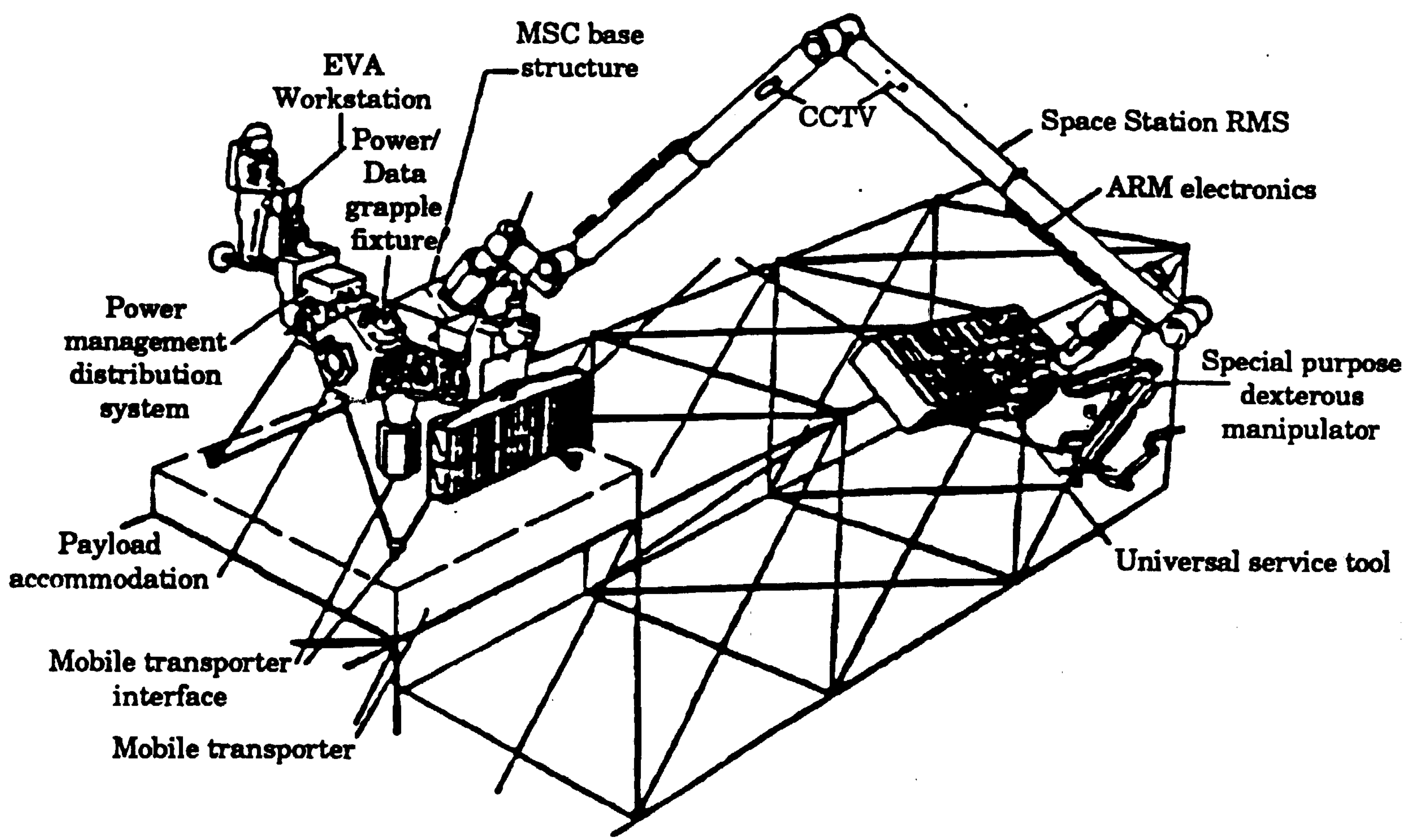

Figure 2-3. Mobile Servicing Center

3.0 High Voltage Power Supply Test Facility Conceptual Design

The conceptual block diagram for a high voltage power supply (HVPS) test facility which will be flown as a space station attached payload experiment is shown in Figure 3-1. This is a complete 60 GHz communication package including a high voltage TWTA which can communicate with another spacecraft. The prime co-orbiting spacecraft candidate is AXAF which also has the same basic 60 GHz communication system as in the space station attached payload experiment.

The high voltage power supply for operating a 60 GHz TWT in the HVPS experiment will be designed to use space vacuum as the high voltage insulation system.

There is a diagnostic package to evaluate interactions between the high voltage power supply test facility and both the natural and induced environments. Space is not a pure vacuum and plasma particles may affect high voltage operations. It is important to document the interactions even if they do not change the system performance.

A command and data processor system is included to operate and monitor the HVPS, the 60 GHz communication system and the diagnostics package. It will provide the correct interface with the space station Attached Payload Accommodations Equipment (APAE) and Data Management System (DMS).

The associated experiment hardware has its own enclosure for transportation in the shuttle and for integration on the attached payload assembly with other scientific experiments.

The power, data and thermal interfaces with the space station are identified. Warning lights have been included on the outside of the enclosure to ensure safety for personnel during EVA or during the shuttle or OMV approach to the space station.

Figure 3-2 shows the electrical power subsystem block diagram. 28 vdc from the APAE is used to supply the HVPS, the communications package, diagnostics package and the data management system.

Figure 3-3 shows the proposed enclosure for the HVPS test facility. It is based on a standard MMS equipment enclosure and has the dimensions of 47 inches (120 cm) by 63.6 inches (161.5 cm) by 18 inches (45.7 cm) height. It has its own thermal control system with the top surface louvers.

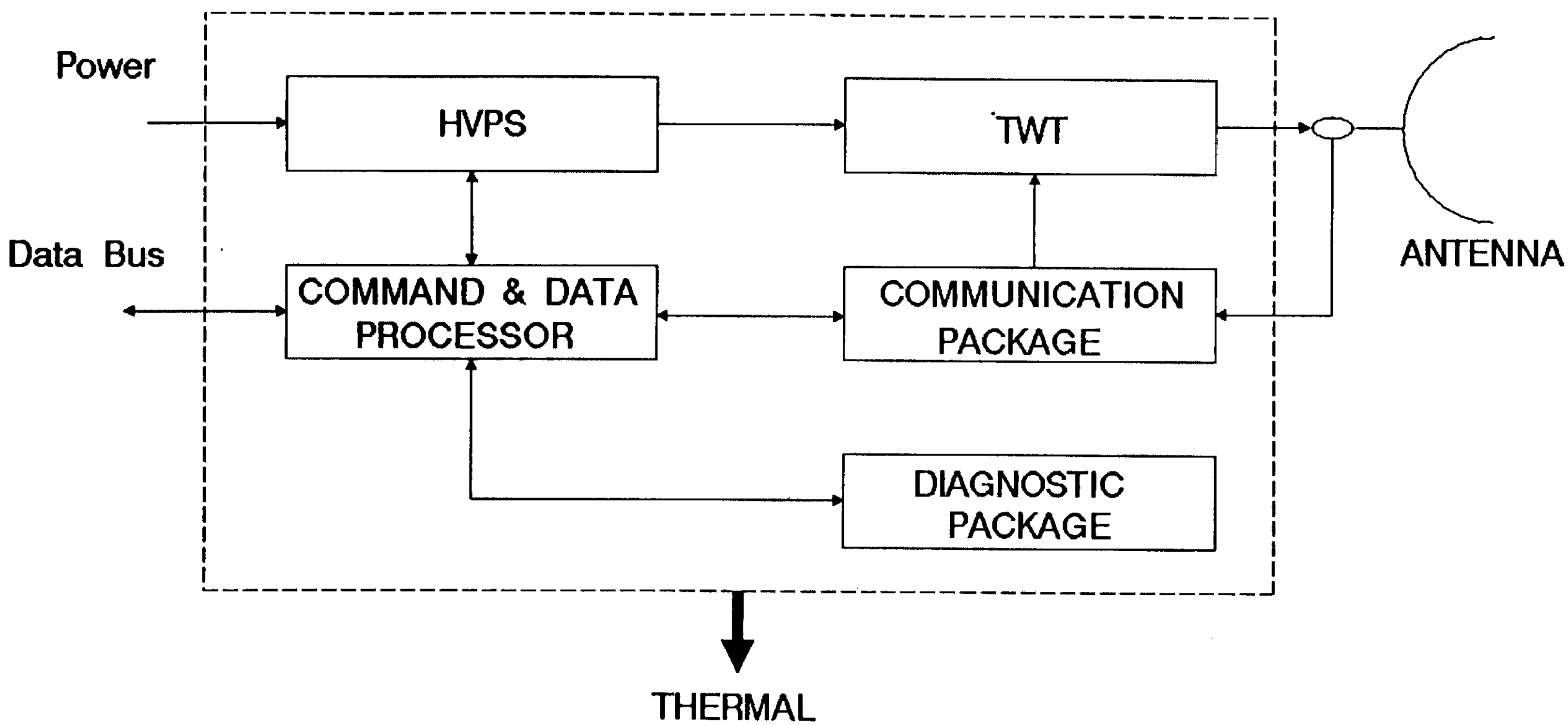

Figure 3-1. High Voltage Power Supply Test Facility Block Diagram

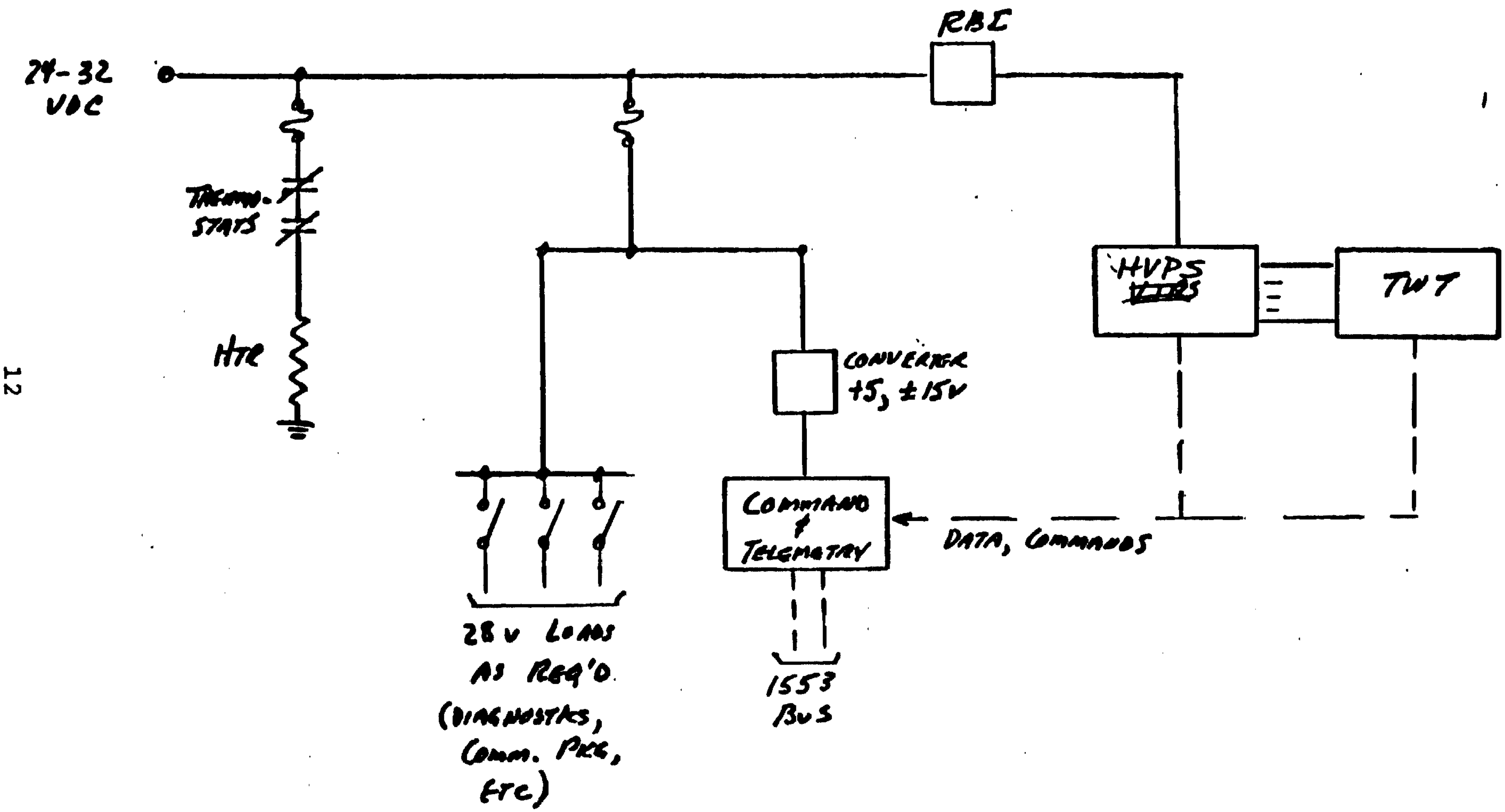

Figure 3-2. HVPS Test Facility EPS Block Diagram

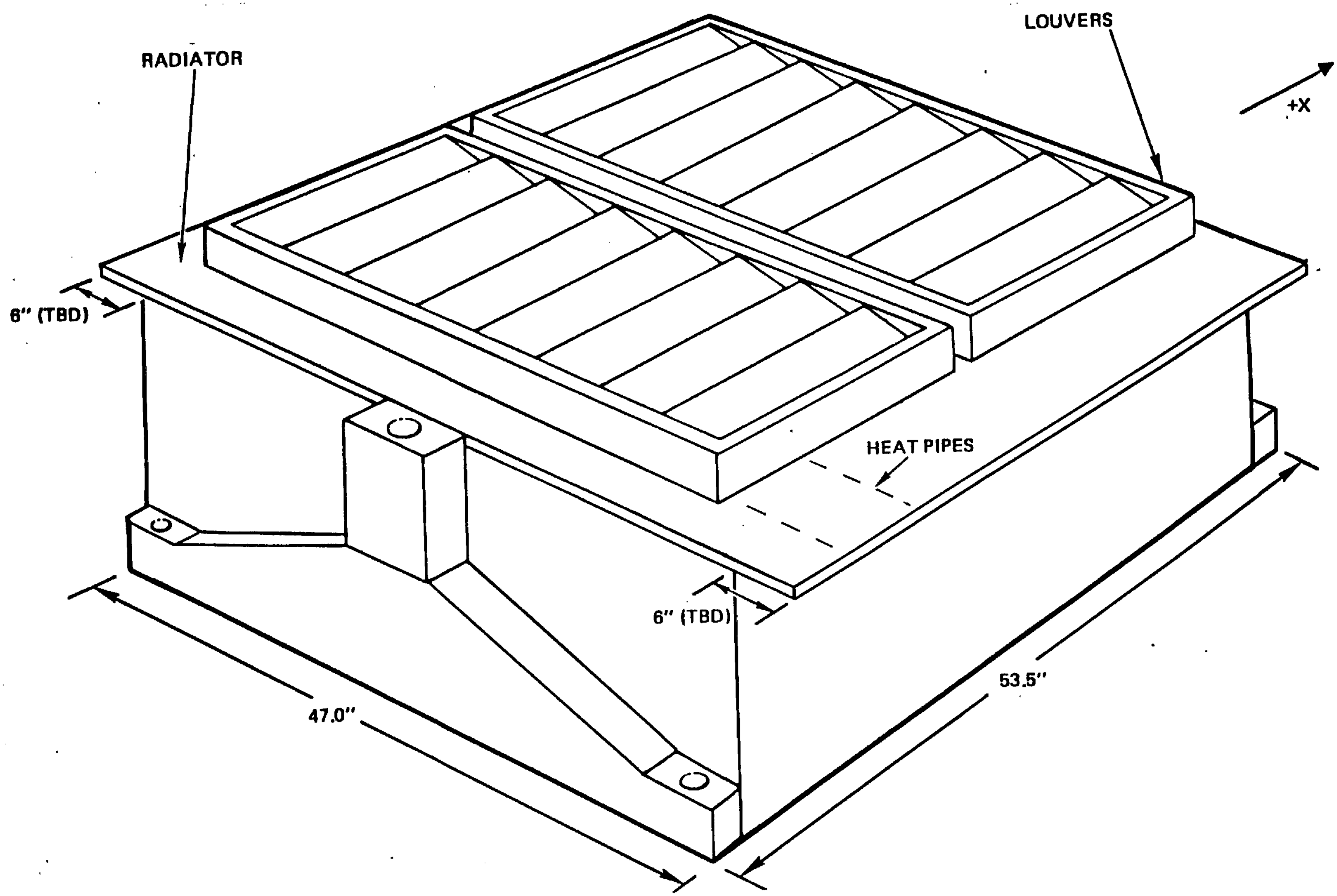

Figure 3-3. Flight Qualified Standard MMS Box

Figure 3-4 shows the interior layout of the experiment hardware for the four possible options.

Figure 3-5 shows the location of the space station program elements. There are three APAE elements located on the upper space station truss and two APAE elements located on the lower space station truss. The HVPS test facility will be located on the upper truss in order to best communicate with the AXAF co-orbiting platform.

3.1 High Voltage Power Supply (HVPS)

The HVPS conditions the space station APAE power source (28 vdc) to the high voltage electrical requirements of the 60 GHz TWT. The reliability of the high voltage electronics has been a major problem area in space communication systems. The lower frequency RF transmitters are presently being developed with low voltage solid state amplifiers with their attendant lower efficiency in the 10 to 25%. At the higher frequencies, the solid state amplifier efficiency is further reduced and the RF power level is low. The presently developed 60 GHz TWT requires minus 18 KV for its operation with an operational efficiency of 40%.

Figure 3.1-1 shows a detailed block diagram of the HVPS with its electrical interface with the 60 GHz TWT. Figure 3.1-2 shows the electrical interface diagram with the proposed commands and telemetry signals that will evaluate the electrical performance of the HVPS and the TWT loading.

28 vdc from the space station APAE goes into two input filters: (1) auxiliary input filter and (2) main input filter. The auxiliary input filter provides power to the auxiliary power inverter/converter which provides regulated power to the internal control logic electronics, ac power to the TWT heater circuit, to the anode supply and to the ion pump supply.

The main power goes into the high voltage inverter and the high voltage output power transformer-rectifier-filter network and supplies the high power TWT cathode and depressed collectors.

The command sequence is to first go to the standby mode where the auxiliary inverter/converter is turned on and allows the heater to go into the warm up mode, the ion pump supplies to turn on and the anode supply to turn on. After the 5 minute timer has operated, the operate command can be sent to turn on the main power inverter and the high voltage outputs.

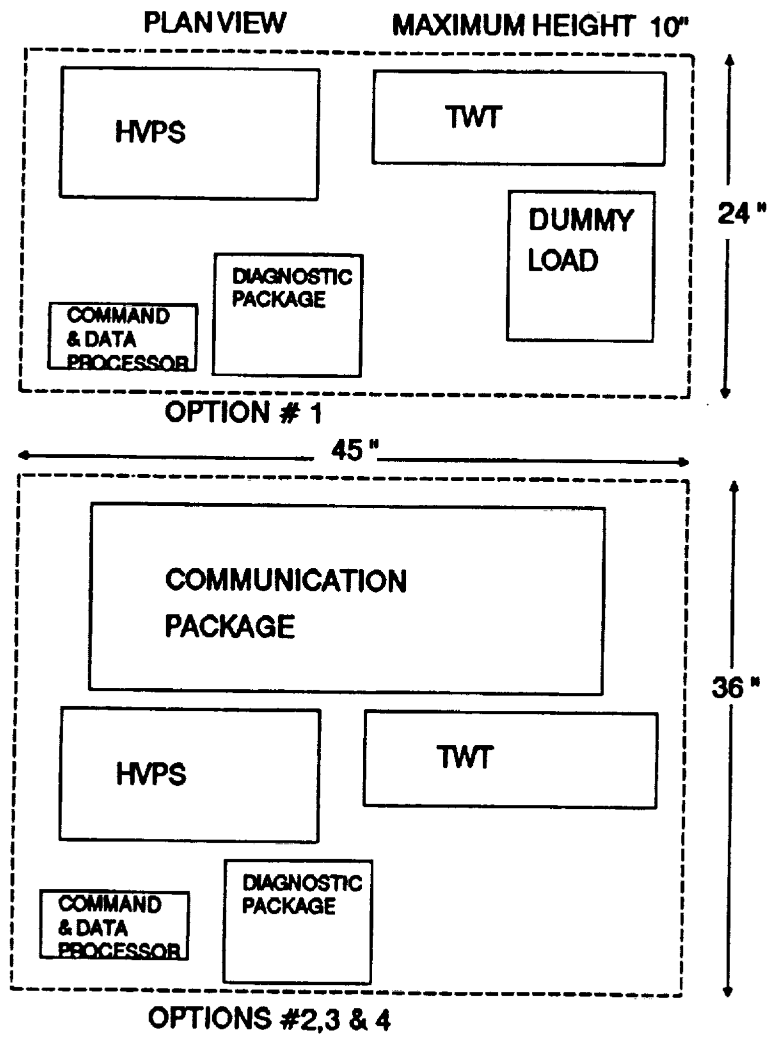

Figure 3-4. HVPS Test Facility Size Estimate

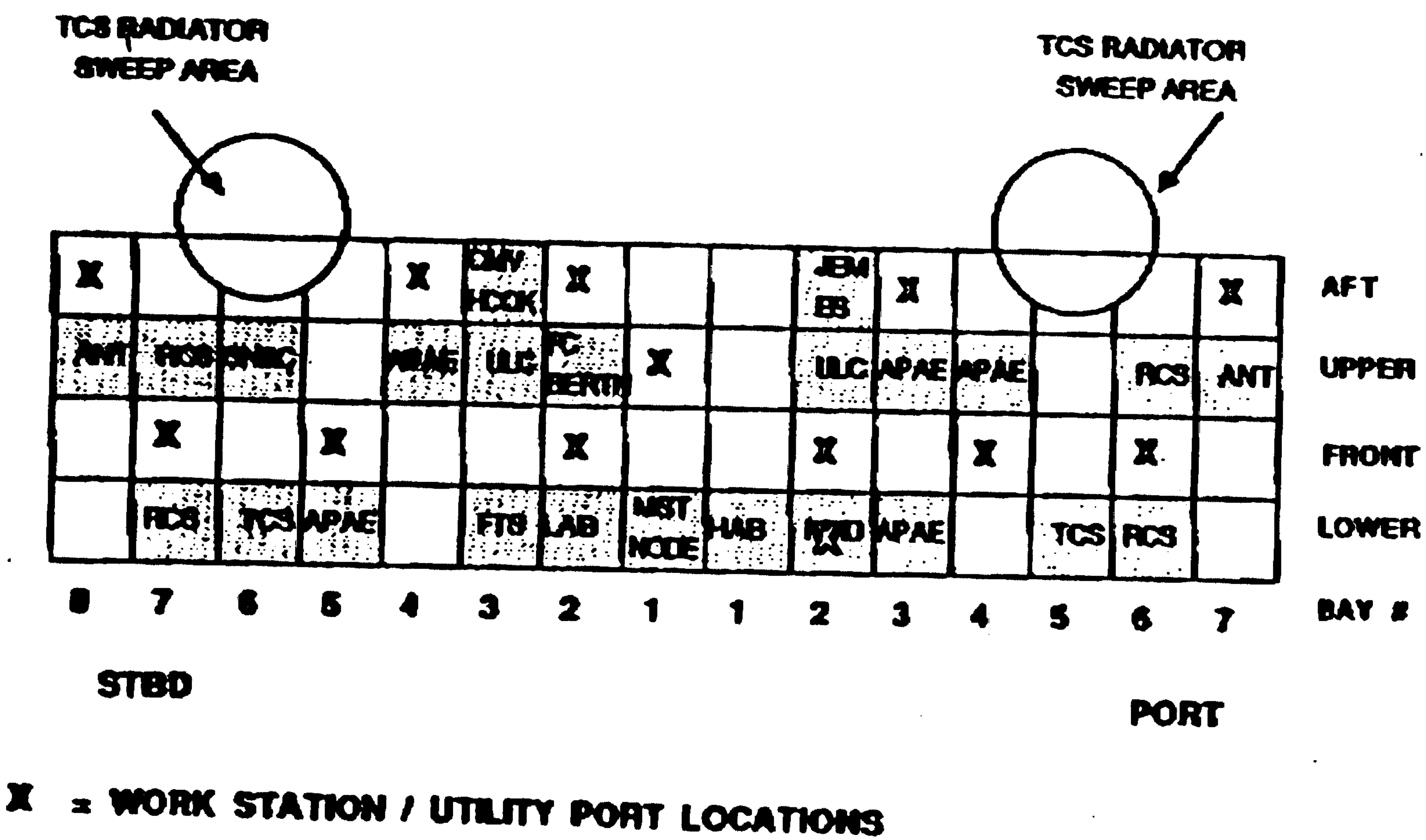

Figure 3-5. Location of Space Station Program Elements

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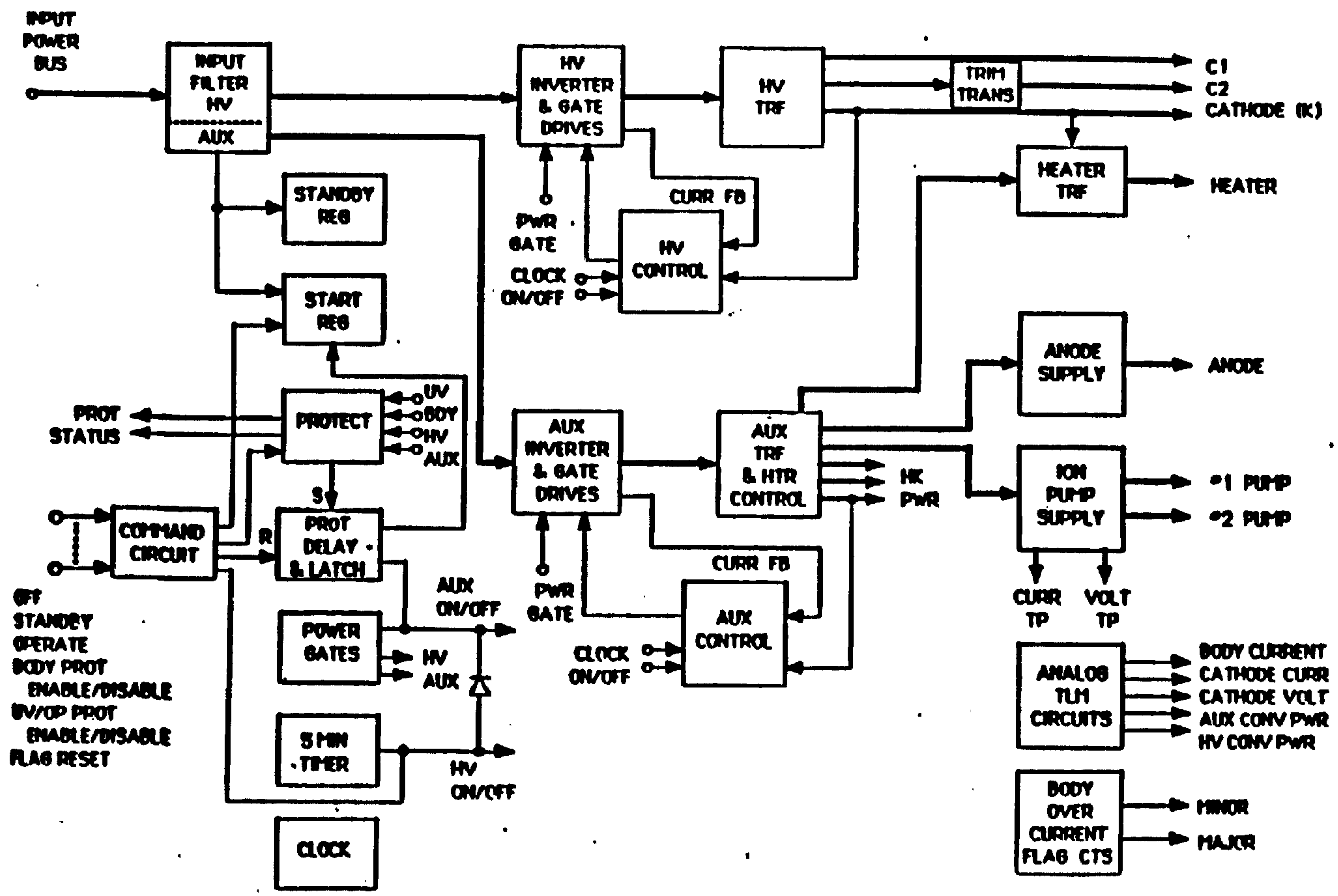

Figure 3.1-1. HVPS Block Diagram

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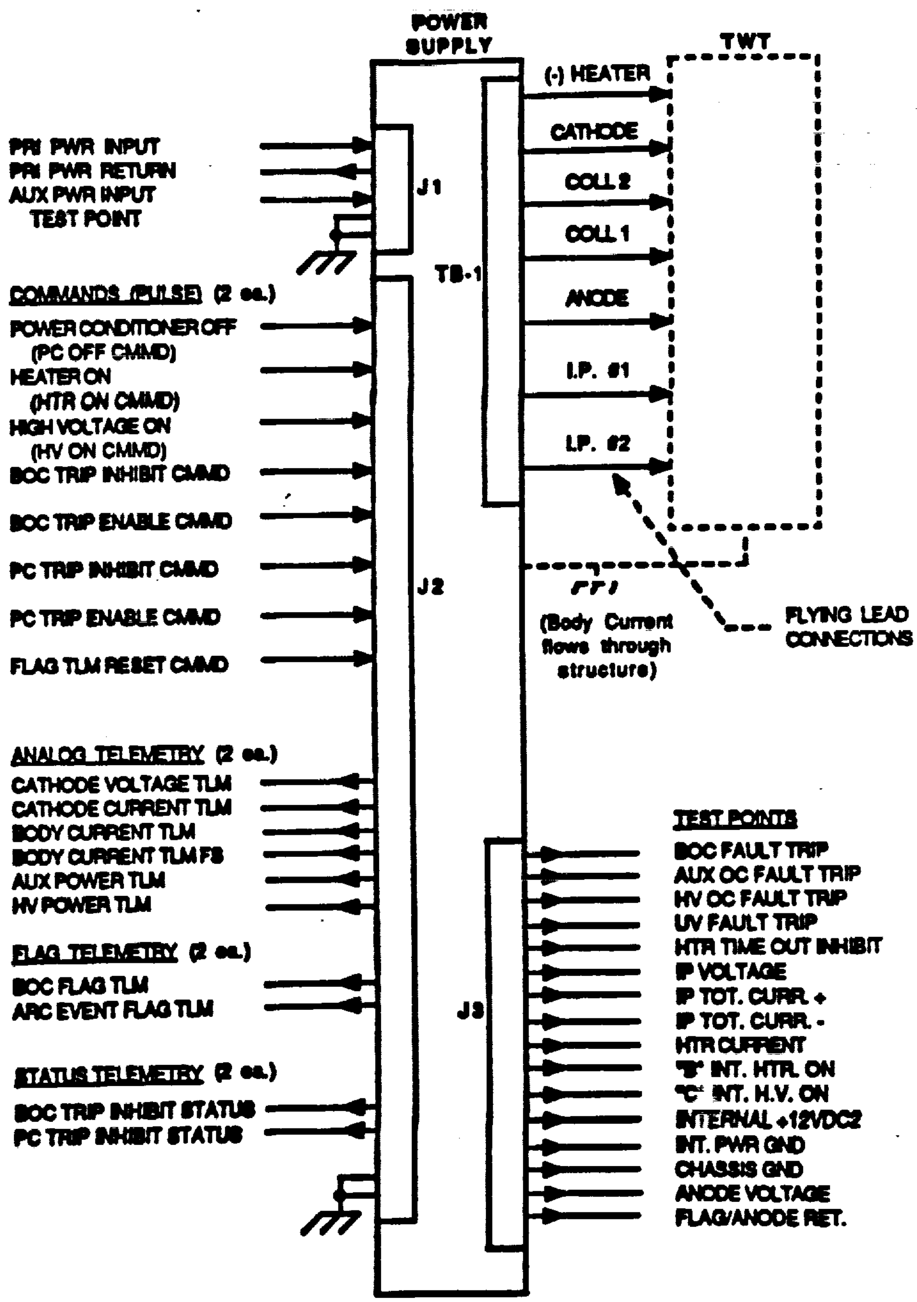


Figure 3.1-2. HVPS Electrical Interface Diagram

Additional command capabilities are; (1) the body protection enable/disable command; (2) the under-voltage and overpower protection enable/disable and (3) the protection flag reset.

The protection system includes the following functions:

Input under-voltage
TWT body/helix over-current
High voltage low
High auxiliary input power.

These protection circuits can turn off the main power converter and the auxiliary power converter to an off mode to ensure that the TWT cannot be damaged due to possible out-of-tolerance operation and excessive body current due to TWT defocusing.

Figure 3.1-3 shows the switch mode power stage topology for the main power converter. It is a current fed series inductor switch mode dc-dc converter where the series power inductor provides inherent power source current limit during startup, output overloads and output high voltage arcs. The control logic senses the peak current in the power switches and provides instantaneous turn off when a switch peak current level has been sensed. The converter is designed to operate continuously in a short circuit mode and provides maximum protection of the power semiconductors and maximizes the power converter reliability.

The high voltage filter capacitors have a current limiting resistor in series both to limit the peak discharge current to about 100 amps and to control where the transient high voltage appears on the series resistor and not on any ground return lines.

An alternate power stage topology is presented in Figure 3.1-4 which is presently being developed on a TRW IRAD project. It is a resonant topology where the input series inductor is resonated with the reflected capacitance of the high voltage transformer and output rectifier diodes. A voltage multiplier rectifier-filter network is also used to reduce the high voltage requirement of the output power transformer. This power stage topology is being developed because it can operate at 100Khz which is above the 30 KHZ limit of the standard switch mode topology and has an operating efficiency of 90% compared to the 85% efficiency of the switch mode circuit topology presently being used in the TWT power supplies.

The mechanical, thermal and high voltage insulation design are also very important in order to maintain the high reliability of the high voltage power supply. The HVPS is divided up into two isolated sections: (1) low voltage electronics and (2) the high voltage electronics as shown in Figure 3.1-5. This is done so that if there is an arc in the high voltage section, it cannot arc over to any low voltage components and cause a low voltage component to fail. The power stage electronics are designed for short circuit operation and there is no component over-stress.

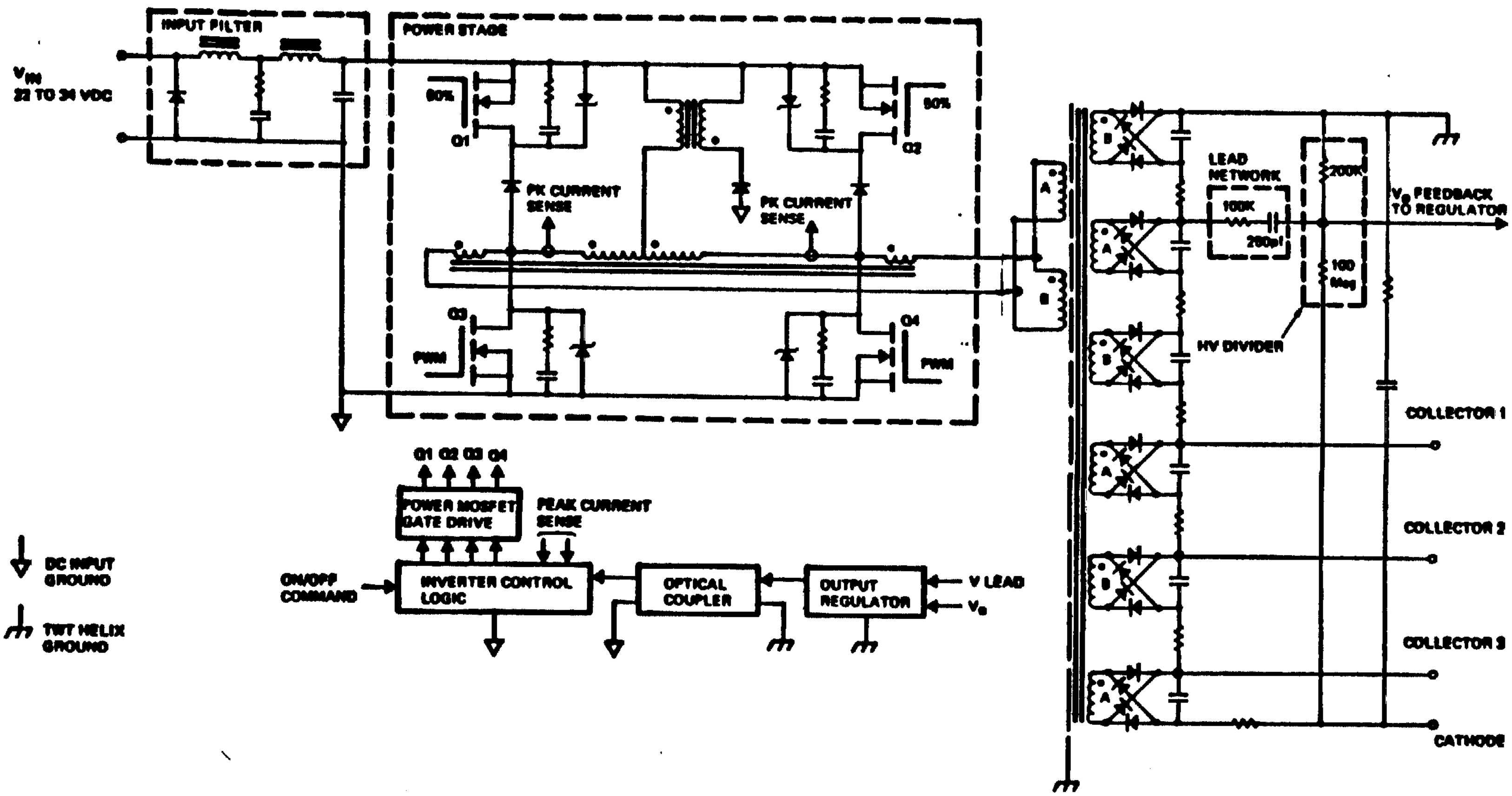
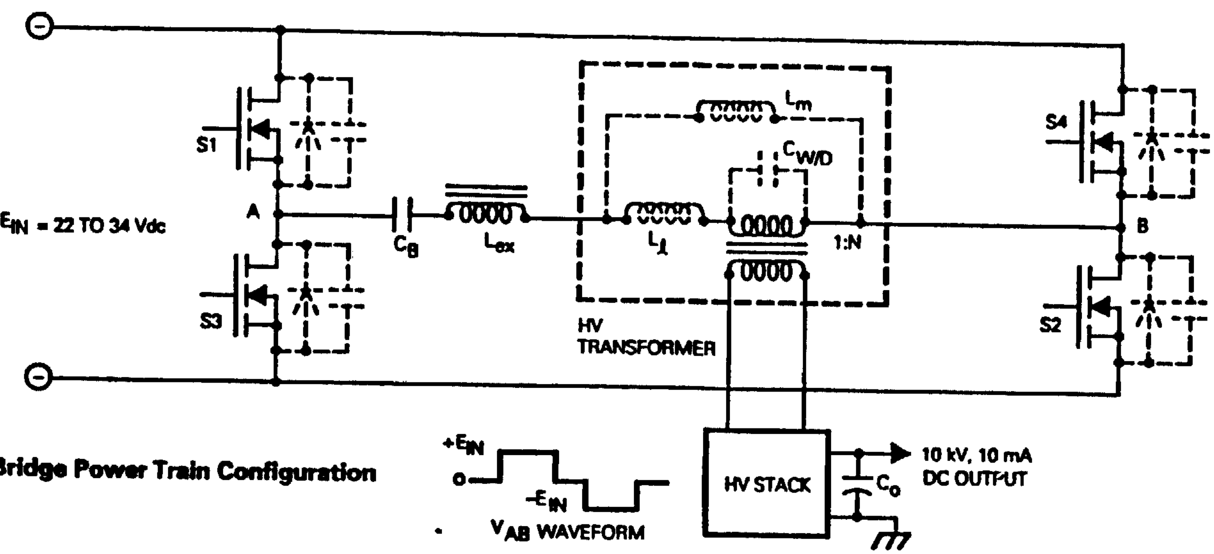
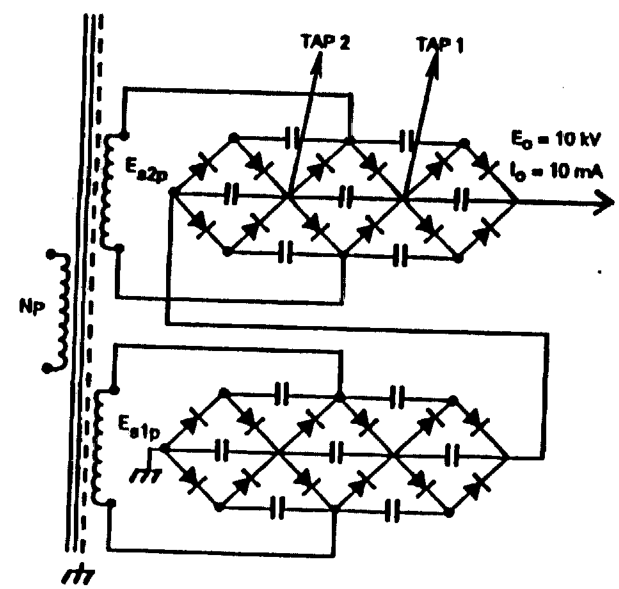


Figure 3.1-3. Switch Mode Power Stage Topology



Parallel Resonant Full-Bridge Power Train Configuration



DUAL SERIES VOLTAGE TRIPLER MULTIPLIER (X6)

Figure 3.1-4. Parallel Resonant Power Stage Topology

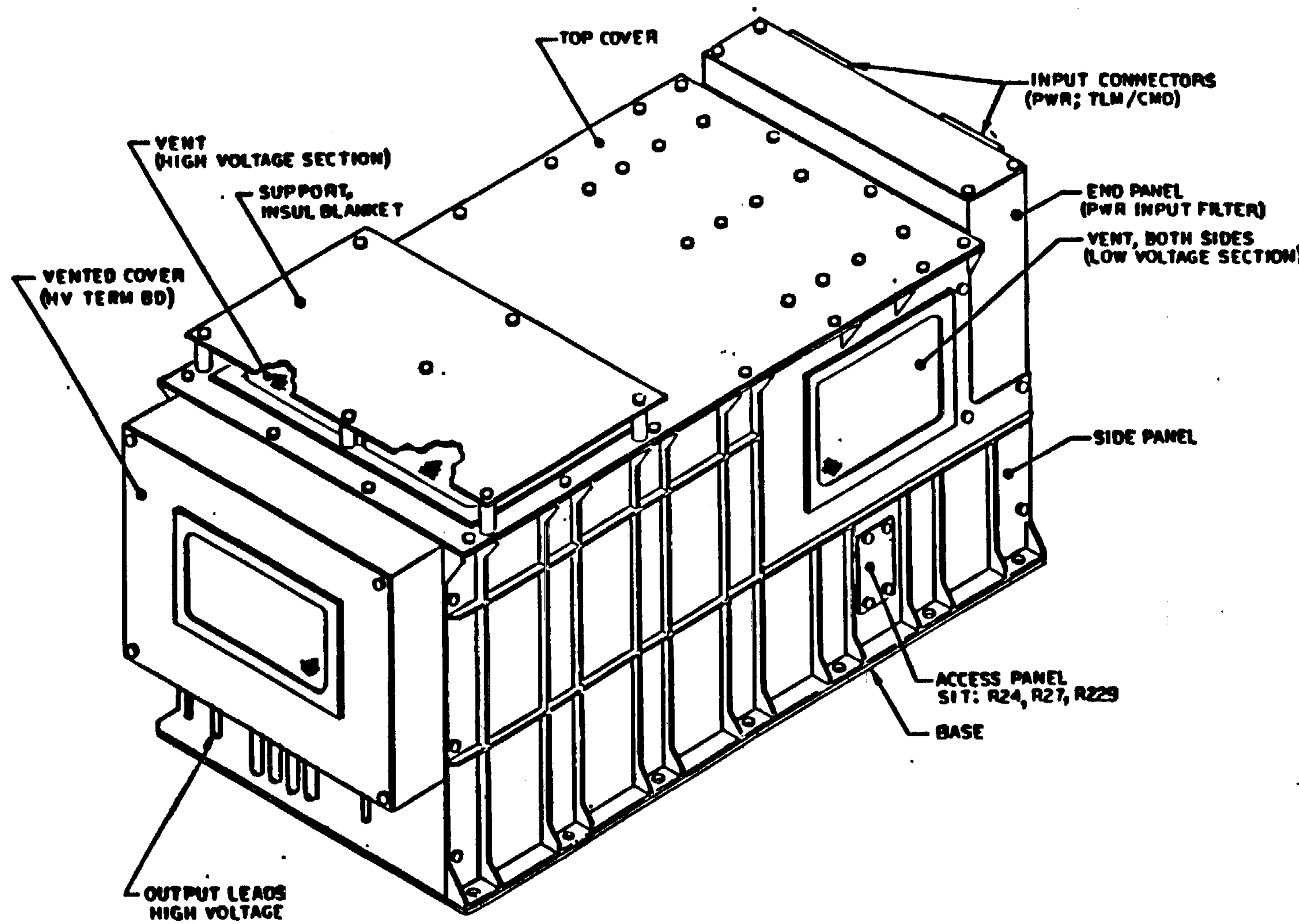


Figure 3.1-5. HVPS Mechanical Assembly

Figure 3.1-6 shows the HVPS outline drawing. Table 3.1-1 summarizes the HVPS mechanical design data. It shows an example of a HVPS assembly that would fulfill the experiment requirements. three screened vents are used for three areas: (1) low voltage electronics section; (2) high voltage electronics section and (3) HVPS and TWT cable interconnection chamber. A high voltage connector is not used because of the high voltage connector reliability. Figure 3.1-6 also illustrates the interconnection technique that is used to make the TWT electrical connectors after the HVPS acceptance testing.

It is proposed that baffle plates be placed over the three screen area as part of the high voltage diagnostic package in order to understand the space plasma interaction with the HVPS electronics.

Figure 3.1-7 shows an example of a development high voltage component board where there is a barrier on the mounting edge to increase the board surface creepage and a beryllium oxide insulator used to conduct the heat from the high voltage diode to the mounting flange of the high voltage component board. The high voltage components are bonded to the high voltage board. Stainless steel corona balls are used over each electrical connections in order to control the electric field from the connections.

Beryllium oxide insulators are used to conduct heat from the high voltage components such as diodes and resistors.

The following high voltage insulation guide lines are used for the layout of the high voltage component board:

surface creepage - 8 volts per mil

dielectric stress on air or vacuum - 15 volts per mil

dielectric stress through solid insulation materials - 200 volts per mil.

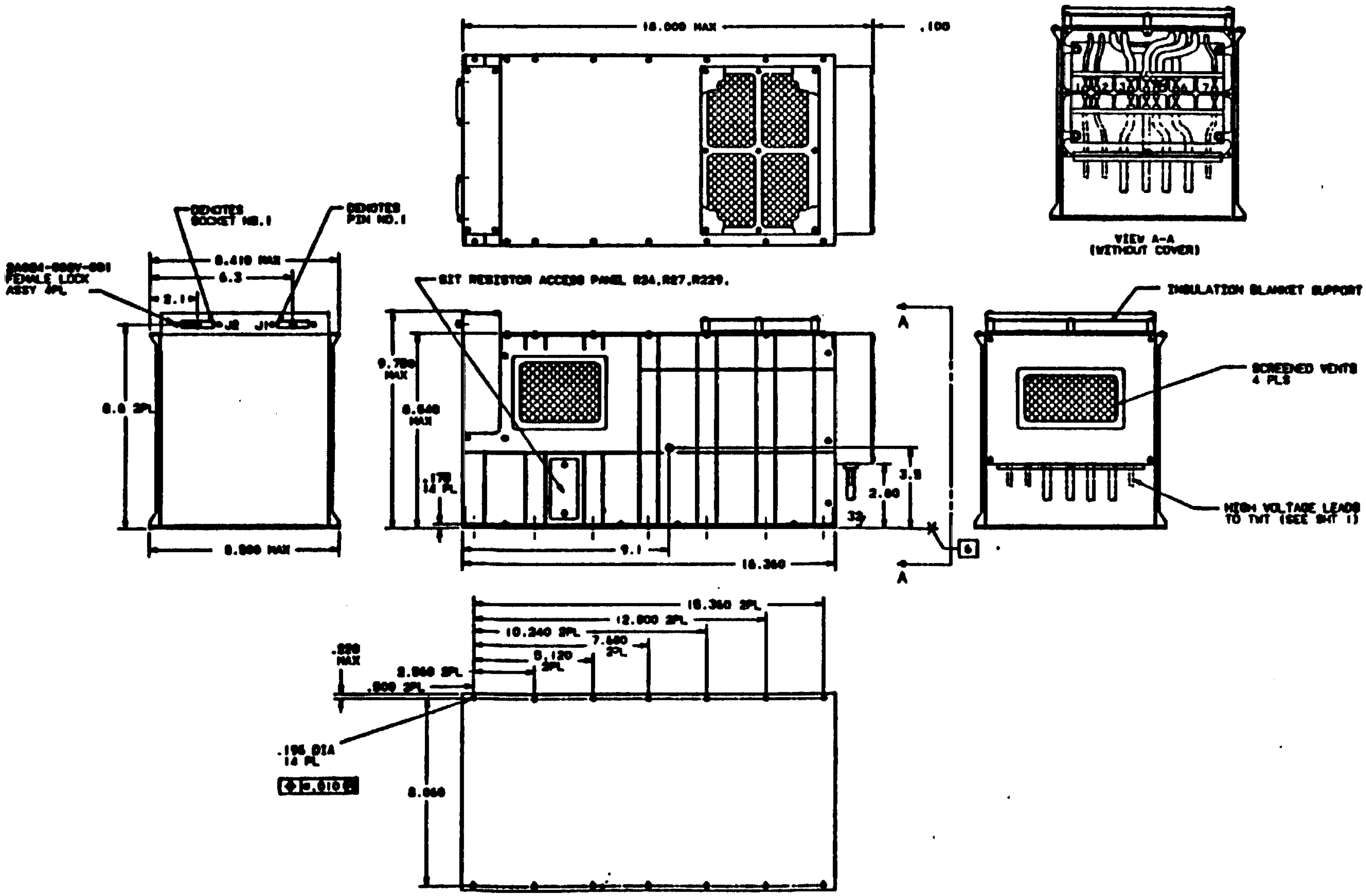


Figure 3.1-6. HVPS Mechanical Dimensions

Table 3.1-1. HVPS Mechanical Design Data

SIZE (IN.):	9.75H X 8.50W X 18.00L
WEIGHT:	28 LBS
VOLUME:	1052 IN^3 (COMP. ENCLOSURE)
BASEPLATE AREA:	139.06 IN^2
POWER DISSIPATION:	86.65W
B/P THERMAL DENSITY:	0.62W/IN^2
COMPONENT COUNT:	728
UNIT DENSITY:	.027 LB/IN^3 (COMP. ENCLOSURE)
COMPONENT DENSITY:	.70 PART/IN^3 (COMP. ENCLOSURE)
LV VENT (A/V):	8.61 CM^2/LITER
HV VENT (A/V):	6.78 CM^2/LITER
TB1 VENT (A/V):	17.5 CM^2/LITER
VENT SCREEN:	34% OPENING, 70 MICRON RATING
HV PACKAGING LAYOUT:	8V/MIL SURFACE CREEP 15V/MIL AIR (SPACE) GAP 100V/MIL MATERIAL DIELECTRIC

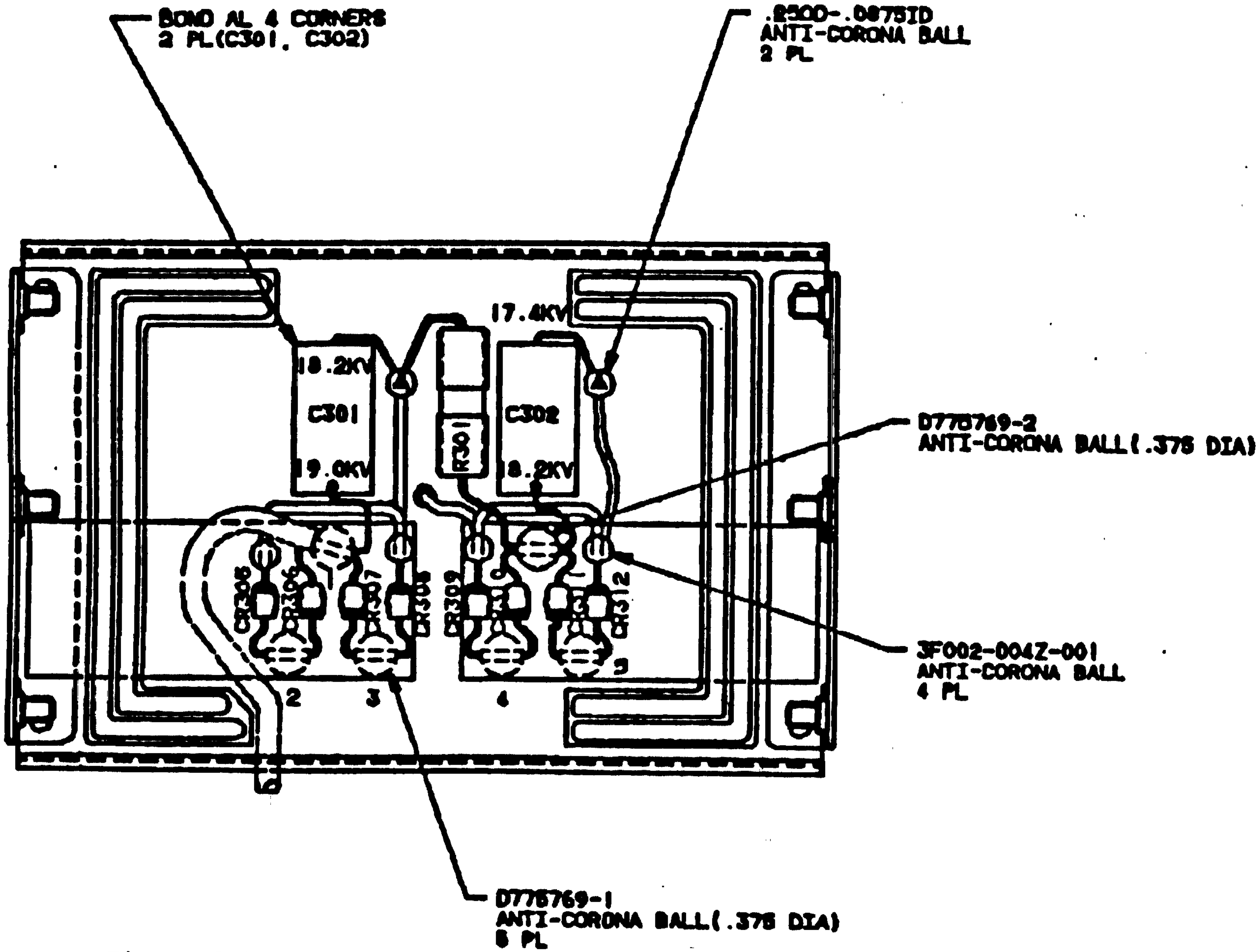


Figure 3.1-7. High Voltage Component Board Assembly

3.2 60 GHz Traveling Wave Tube (TWT)

The 60 GHz traveling wave tube is presently being developed by Hughes Aircraft Company, Electron Dynamics Division for NASA Lewis Research Center under contracts NAS3-23351 (Proof of Concept TWT) and NAS3-25090 (Advanced Development Model TWT). The proof of concept contract was completed in June 1988. NASA Contractor Report 182135 "Development of a 75 Watt 60 GHz Traveling Wave Tube for Intersatellite Communications" provides the design and test data for the initial 60 GHz TWT. The Advanced Development Model TWT contract is still in progress and should be completed in late 1990.

The 60 GHz TWT will be used as the load on the HVPS discussed in section 4.0. The TWT operates at a nominal - 20 KV voltage because of the TWT electrical configuration necessary for a 75 watt RF 60 GHz operation. The TWT has multiple depressed collectors to maintain the TWT efficiency at 40%.

E5560

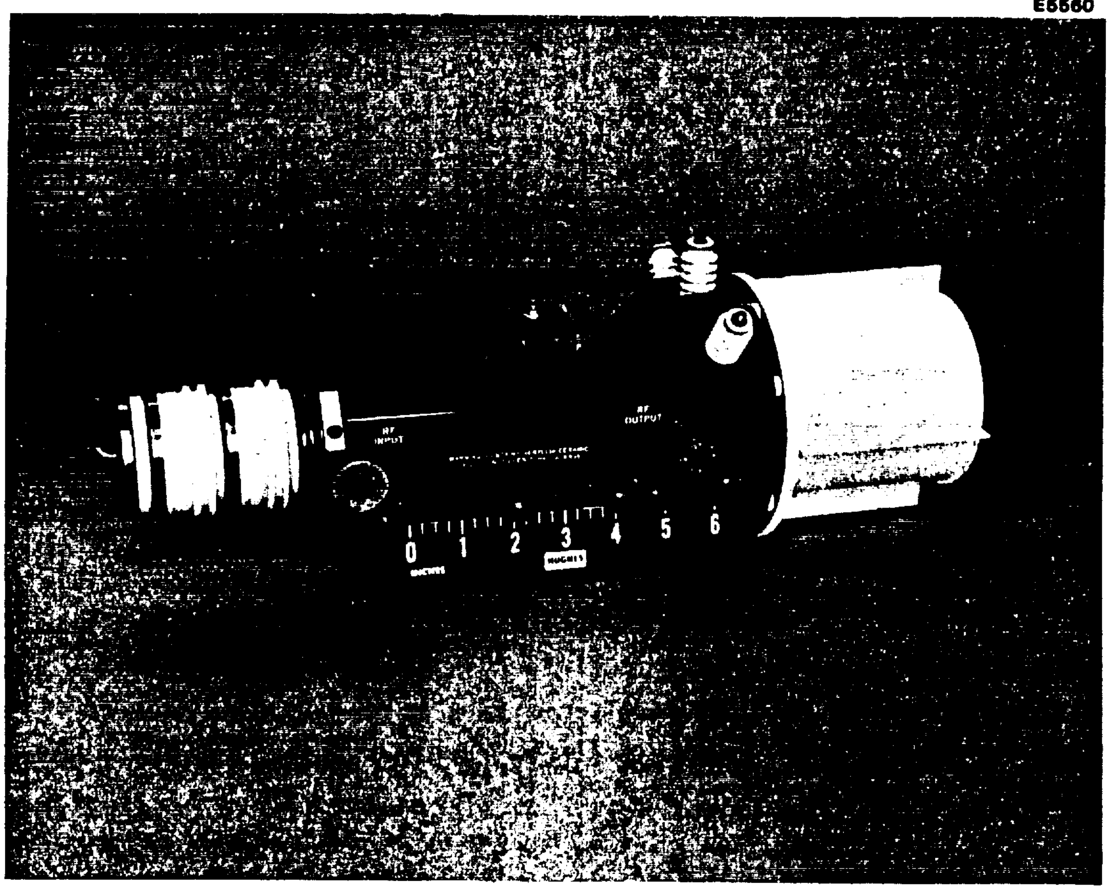


Figure 3.2-1. Experimental 60 GHz TWT Model Assembly

Table 3.2-1 lists the electrical and RF specifications for the development TWT. Figure 3.2-1 shows a packaged experimental model TWT built on the initial proof of concept contract. The flight model 60 GHz TWT will have to be modified to cover the exposed high voltage TWT terminations to ensure that there will not be any discharges to the HVPS test facility hardware and to be compatible with the proposed HVPS test facility thermal control system.

Table 3.2-1. TWT Specifications

RF Characteristics	
Power output at saturation	75 watts
Frequency	59 to 64 GHz
Gain at saturation	35 dB (minimum)
Duty cycle	CW
Overall efficiency	40% at saturation
Electrical Characteristics	
Cathode voltage	-20 kV (maximum)
Cathode current	0.070 A
Body Current	0.003 A
Collector voltages	5 stages (maximum)
Anode voltage	+200 V
Anode current	0.001 A
Filament voltage	6.5 V nominal
Filament current	0.5 A nominal
Ion-pump voltage	3.0 +/-0.3 kV
Ion-pump current	<10 micro A
Mechanical Characteristics	
Focusing	Periodic permanent magnetics
Cooling	Conduction and radiation cooled collectors
Weight	15 pounds

3.3 Communication Experiment Conceptual Definition

Trade studies, requirements and supplementary material related to the concept definition are presented. The conceptual design of proposed 60 GHz communication package and the 60 GHz RF communication hardware technology status and needs are than presented.

3.3.1 Trade Studies

3.3.1.1 Test Option Trades

The HVPS test facility development and planned testing of an integrated traveling wave tube and power supply on-board the space station offers an opportunity of conducting some related tests in the low earth environment with minimal additional costs. Four test options were formulated and considered as listed in Table 3.3-1 Experiment Options and Major Requirements.

The first option is the basic high voltage power supply test employing an integrated traveling wave tube. This tube is operated without RF drive as a constant load to the power supply unit. This basic test is the primary purpose of the planned test facility and has been defined in detail.

The second option is to test the integrated unit as a high power amplifier. It would be the first test of this kind performed in the space environment. It also offers the opportunity to observe deterioration of the TWTA including both tube and power supply in a space environment and to determine the cause of failure at the end of the life of the test unit. The information so obtained will be of tremendous value for TWTA design improvement and life prediction.

The tube will be operated at back-off power level continuously with the following parameters monitored.

1. Cathode current
2. Body current
3. Current of each collector
4. Power supply voltages
5. RF drive and TWTA output

Periodically, the following checks and tests will be conducted:

1. Voltage standing wave ratios,input and output
2. Power input, output, and saturated power
3. Frequency response, linear and saturated
4. Phase vs drive
5. Third order intermodulations

These tests will be performed by ground command with analyses of telemetry data done on ground.

Table 3.3-1. Experiment Options and Major Requirements

NO.	EXPERIMENT OPTION	OPTION OBJECTIVES	TEST FEATURES	MAJOR REQUIREMENTS	REMARKS
1	HVPS/TWT INTEGRATED TEST	o HVPS PERFORMANCE MEASUREMENTS IN LEO ENVIRONMENT o HVPS ON-OFF CYCLING AND LIFETIME TEST	o CONSTANT LOADED HVPS	o INSTRUMENTATION FOR VOLTAGE AND CURRENT MEASUREMENTS o VOLTAGE ADJUSTMENTS AND ON-OFF CYCLING o TEMPERATURE SENSING AND TRIP VOLTAGE AND CURRENTS TRIP CIRCUITS o TLM/CMD INTERFACE WITH DMS/SS THROUGH C&DH/HVPSTF	o BASIC SPACEBORNE HVPS TESTING o TWT WITHOUT RF EXCITATION AS A CONSTANT LOAD TO HVPS o HVPS LIFETIME AND CAUSE OF FAILURE OBSERVATION POSSIBLE ONLY FOR TWT OUTLAST HVPS
2	TWTA TEST	o OBJECTIVES OF OPTION NO. 1 o 60 GHz TWTA CHARACTERISTICS & PERFORMANCE MEASUREMENT IN LEO ENVIRONMENT o TWTA LIFETIME TEST	o VARIABLE LOADED HVPS BY VARYING TWTA RF DRIVE o MEASURE TWTA MAJOR PARAMETERS o OBSERVE TWTA DECAYING AND UNIT LIFETIME o DETERMINE CAUSE OF FAILURE	o OPTION NO. 1 REQUIREMENTS o TUNABLE RF DRIVER WITH ADJUSTABLE OUTPUT o DUMMY LOAD FOR TWTA o TWTA SENSING AND PROTECTION CIRCUITS o ADDITIONAL TLM/CMD REQUIREMENTS FOR TWTA DATA COLLECTION AND TEST CONTROL	o TWT WITH ADJUSTABLE RF DRIVE AS VARIABLE LOAD TO THE HVPS - MORE REALISTIC HVPS TEST o OPPORTUNITY OF TWTA PERFORMANCE MEASUREMENT IN THE SPACE WITH WITH MINIMUM ADDITIONAL COST o OPPORTUNITY OF OBSERVATION TWTA DETERIORATION AND DETERMINATION OF CAUSE OF FAILURE IN SPACE
3	60 GHz TRANSMISSION TEST	o OBJECTIVES OF OPTION NO. 2 o 60 GHz TRANSMISSION TEST IN LEO ENVIRONMENT o SPACE TEST OF 60 GHz COMPONENTS	o FEATURES OF OPTION NO. 2 o IN-SITE 60 GHz TRANSMISSION MEASUREMENT o TRANSMISSION RANGE LIMITED BY THE LENGTH OF SS (0.3 X 10^6 WAVELENGTH)	o OPTION NO. 2 REQUIREMENTS o SIMPLE HORN RADIATOR, DUMMY LOAD, AND POWER DIVIDER o RECEIVING TERMINAL AND INSTRUMENTATION FOR POWER LEVER MEASUREMENTS o ADDITIONAL TLM/CMD FOR TRANSMISSION DATA COLLECTIO AND TEST CONTROL o ADDITIONAL GROUND ANALYSIS FOR TRANSMISSION DATA	o OPPORTUNITY OF IN-SITE 60 GHz TRANSMISSION MEASUREMENT o RADIATION POWER LEVEL CONTROL FOR SS RF ENVIRONMENT o MINIMAL ADDITIONAL COST FOR RECEIVING POWER MEASUREMENT INSTRUMENTATION o OPPORTUNITY OF SPACE TEST OF SOME 60 GHz COMPONENTS
4	60 GHz COMMUNICATIONS SYSTEM TEST	o OBJECTIVES OF OPTION NO. 2 o 60 GHz CROSSLINK COMMUNICATIONS SYSTEM TEST o CROSSLINK ANTENNA POINTING AND TRACKING CAPABILITY DEMONSTRATION	o FEATURES OF OPTION NO. 2 o CROSSLINK SYSTEM TEST WITH BOTH TERMINALS IN CONSTANT MOTION (EXCEPT TDRS AS ANOTHER TERMINAL)	o OPTION NO. 2 REQUIREMENTS o COMPLETE TRANSMITTER PACKAGE WITH TWTA AS POWER AMPLIFIER o COMPLETE RECEIVER PACKAGE o PARABOLIC DISH ANTENNA WITH FRONT-END ELECTRONICS MOUNTED ON EPA/SS (SUBOPTION 4A) o PARABOLIC DISH ANTENNA WITH MONOPULSE FEED FOR AUTOTRACK (SUBOPTION 4B) o ADDITIONAL TLM/CMD FOR SYSTEM TEST DATA COLLECTION AND TEST CONTROL	o OPPORTUNITY OF 60 GHz CROSSLINK COMMUNICATION SYSTEM TEST - PLATFORM CANDIDATES FOR OTHER END INCLUDING TDRS, SHUTTLE, COP OR POP o THE POINTING CAPABILITY OF EPA/SS MAY BE EMPLOYED IN LIEU OF ANTENNA POINTINT & TRACKING CAPABILITY o COST OF COMPLETE COMMUNICATIONS SYSTEM - ASSEMBLY OF AVAILABLE COMPONENTS WITH SOME DEVELOPMENT EFFORT

The third option is to employ the TWTA unit of option No. 2 to conduct 60 GHz transmission measurement in situ. A simple power divider and radiation horn will be used to radiate a controlled portion of 60 GHz power amplified by the TWTA. A simple receiving horn and RF power measurement instrumentation located at the far end of the space station longitudinal truss are the minimum additional requirements. A more complex set-up consisting of horn, low noise linear amplifier, down converter (local oscillator and mixer), intermediate frequency amplifier, and detector may be employed to measure received power. This set-up requires a nearly completed 60 GHz receiver and offers opportunity of space test of the 60GHz components. 60 GHz transmission variation with time, location, and altitude can be obtained by analyzing the collected data.

The last option, Option No. 4, is the most interesting and useful one which requires a set of 60 GHz cross-link communications system including a transmitter, a receiver, and an antenna with automatic pointing and tracking capability. Furthermore, a platform is needed to carry the other terminal. The candidate platforms are discussed in the following section.

3.3.1.2 Candidate Platforms Trades

To conduct the 60 GHz communication system test, the space station and another platform is required to carry the two terminals and to provide power, attitude determination, command and telemetry and other test support. The candidate platforms considered, for obvious reasons, are limited to NASA assets as follows:

1. TDRSS or ATDRSS satellite
2. Space Shuttle
3. Orbital Maneuvering Vehicle (OMV)
4. Co-orbiting platform
5. Polar orbit platform

Table 3.3-2 Candidate Platform Trade, tabulated advantages and disadvantages of each candidate. The co-orbiting platform, Advanced X-ray Astrophysics Facility (AXAF), is chosen as the platform to carry the second 60 GHz communication terminal. It is the earliest available platform designed for space station servicing. Furthermore, The AXAF program is presently at its beginning stage: no difficulty is anticipated for accommodating a small 60 GHz cross-link package. Although, according to the current AXAF concept, there is no direct communication requirement between the AXAF and the space station. The communications to and from the AXAF are through MSA and SSA services of TDRSS. The successful 60 GHz cross-link between AXAF and the space station will provide a back-up communications path.

Table 3.3-2. Platform Candidate Trades

PLATFORM	MAJOR FEATURE	ADVANTAGE	DISADVANTAGES	REMARKS
SATELLITE OF EITHER TDRSS OR PLANNED ATDRSS	O 60 GHz PACKAGE PIGGYBACK ON ONE OR MORE OF THE TDRSS/ATDRSS SATELLITES O SEPARATE ANTENNA WITH POINTING AND TRACKING INFORMATION FROM THE DUAL KSA/SSA ANTENNA O SHARE THE DUAL ANTENNA POINTING TO SSMB BY DEVELOPING TRIPLEX FEED	O TDRSS IS ON-GOING PROGRAM; ATDRSS IS PLANNED REPLACEMENT O AT LEAST ONE OF KSA/SS ANTENNA OF ONE OR MORE SATELLITE WILL PROVIDE CONTINUOUS CONTACT WITH SSMB O READY AVAILABLE ANTENNA POINTING AND TRACKING INFORMATION O STATIONARY TDRSS/ATDRSS SATELLITE	O MAJOR IMPACTS AND CHANGES OF DESIGN REQUIRED O RETROFIT OF TDRSS NEAR COMPLETION O POTENTIAL IMPACTS ON TDRSS LAUNCH SCHEDULE O CANNOT DEMONSTRATE FULL COOPERATIVE POINTING AND TRACKING	O LONGEST TEST RANGE OF ALL CANDIDATES
SHUTTLE	O 60 GHz PACKAGE MOUNTED EITHER INSIDE THE CARGO BAY OR AFT FLIGHT DECK O IF ANTENNA AND GIMBAL DRIVE MOUNTED INSIDE THE CARGO BAY; TEST CAN ONLY BE CONDUCTED WITH BAY DOOR OPEN	O READY AVAILABLE POWER, THERMAL, AND AVONICS SUPPORT O MOUNTING PROVISION AVAILABLE O OPPORTUNITY OF TEST	O SHORT TEST PERIODS O DIFFICULT TO SCHEDULE O PACKAGE HAS TO MEET ORBITAL ENVIRONMENT PAYLOAD	O TEST DEPENDS ON ORBITAL SCHEDULE AND MISSION OF FLIGHT
CO-ORBITING PLATFORM (CAP)	O 60 GHz PACKAGE PIGGYBACK ON ONE OF PLANNED CO-ORBITING PLATFORM O COMMAND AND TELEMETRY TO BE INTEGRATED INTO THE PLATFORM SUBSYSTEM	O LONG PERIOD OF TEST O PACKAGE SERVICE OPPORTUNITY WHILE PLATFORM DUCKING WITH SSMB FOR SERVICING O COMPATABLE SCHEDULES (HVPSTF, SSMB AND AXAF)	O MINIMUM IMPACE ON AXAF (SIZE, WEIGHT, POWER) O RELATIVE SHORT TEST RANGE	O BOTH HUBBLE SPACE TELESCOPE AND GAMMA RAY OBSERVATORY ARE COPS BUT TOO LATE TO RETROFIT FOR 60 GHz PACKAGE O ADVANCED X-RAY ASTROPHYSICS PROGRAM JUST BEGINS; ACCOMODATION OF 60 GHz PACKAGE CAN BE MADE WITH MINIMUM IMPACT O SPACE INFARED TELESCOPE FACILITY IS ANOTHER CANDIDATE COP
POLAR ORBITI[illegible]	[illegible]			

3.3.2 60 GHz Communication Experiment Requirements

As presented in section 3.3.1 Trade Studies, the Option No. 4 of communication system test option trade has been chosen for concept definition and the co-orbit platform of the Advanced X-Ray Astrophysics Facility is selected for carrying the other test terminal.

It is assumed that no human intervention on-board either platforms is needed for the test. Furthermore, the direction of system tests and all data analyses are to be performed on the ground. The fall-back Option No. 2 - Integrated TWTA Test is also briefly discussed in Section 3.3.4.

The refined antenna viewing angle requirements and some other requirements which impact test system conceptual design are presented in the following paragraphs.

3.3.2.1 Refined Viewing Angle Requirements

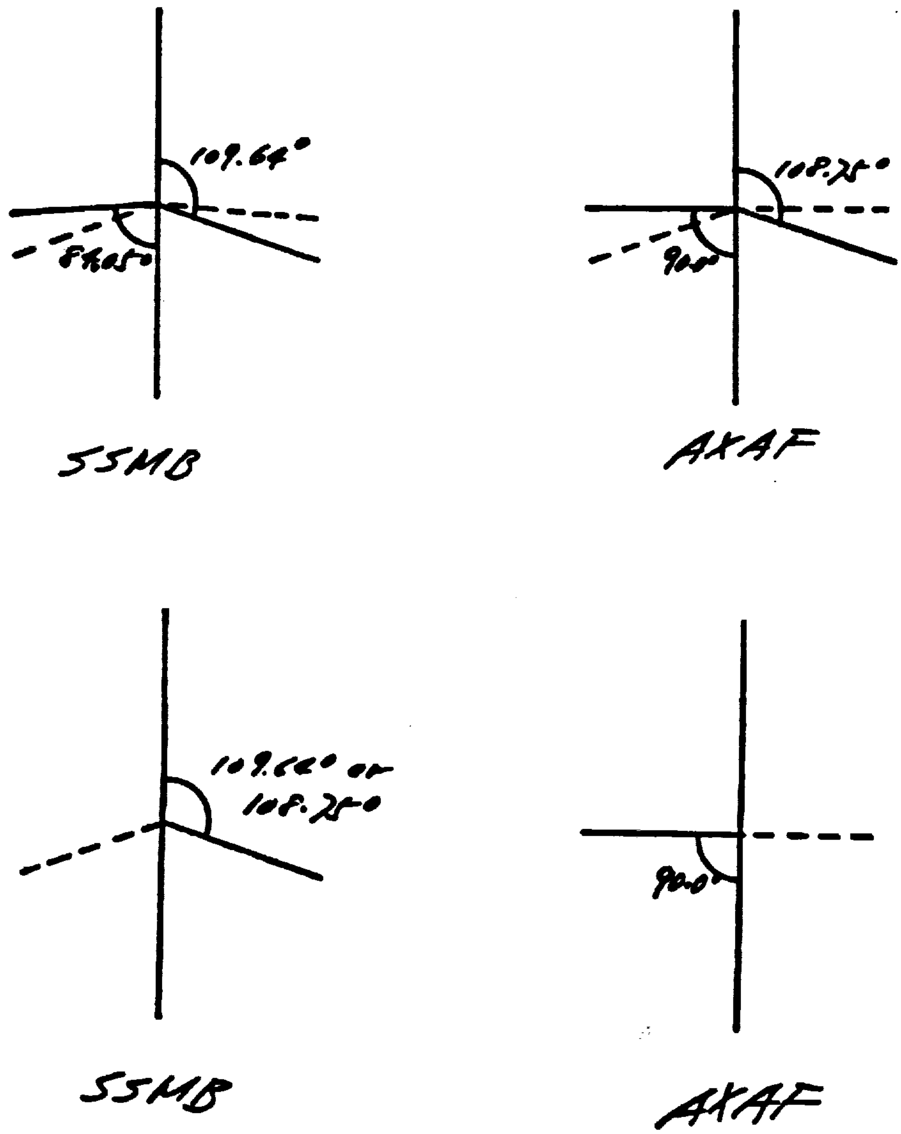
The half-cone viewing angle required for the test terminals on-board the SSMB and AXAF have been determined and presented in the last briefing, and they are 108.75 degrees looking up and 84.05 degrees looking down respectively as shown in the first column of Table 3.3-3. The nominal operating altitude of 463 km for the SSMB and 500 km for the AXAF were employed for the viewing angle computation. However, the potential operating range of altitude for the SSMB and AXAF, as we currently know are 276-500 km and 476-1000 km. The viewing angle requirements for various combinations of extremes of platform operating altitudes were computed and shown in Table 3.3-3, second column to fourth column inclusive. If the proposed communications tests have to be conducted for all time and for all possible platform altitudes then terminal antennas on both the SSMB and AXAF have to be capable of providing spherical coverage as shown in the upper part of Figure 3.3-1. This coverage requirement can be met by either employing a spherical coverage antenna mounted on the tip of a long boom or employing two hemispherical coverage antennas mounted on two diametrically opposite points on the platforms. Considering the following two reasons:

1. Only a very small percentage of time, the AXAF will assume a lower altitude than that of the SSMB, and

2. There are some technical difficulties for providing truly spherical coverage antenna on-board a platform and associated antenna switching and/or signal selection or mixing.

It is recommended that the communication system test set be designed for test only while the AXAF is higher than or at least at the same altitude of the SSMB. With this restriction, the viewing angles for two extreme cases are shown in the last two columns of the Table 3.3-3;

For Combination of operating altitudes



Test only when AXAF is higher than or at least at the same altitude of SSMB

Figure 3.3-1. Antenna Viewing Angle Requirements

1. Both the AXAF and SSMB at an altitude of 463 km (i.e., AXAF altitude range of 463 to 1000 km and SSMB altitude range of 276 to 463 km)

2. Both the AXAF and SSMB at an altitude of 500 (i.e. AXAF altitude range of 500-1000 km and SSMB altitude range 276-500 km)

This does not impose any restriction on platforms operating altitude but limits the test being performed only while the AXAF is at a higher or at least at an equal altitude of that of SSMB. The antenna coverage requirements with the above restriction are shown in the lower part of the Figure 3.3-1. As shown, the AXAF test terminal requires a hemispherical coverage antenna and the SSMB test terminal an antenna with slightly more than a hemispherical coverage. The requirement can be easily met by employing a reflector type antenna with a two-axis gimbal drive.

Table 3.3-3. Viewing Angle Requirements for Combinations of Extreme Operating Altitude

SSMB Altitude (km)	463	276	276	500	500	463	500
AXAF (COP) Altitude (km)	500	463	1000	463	1000	463	500
SSMB Viewing Angle (deg)	108.75 (up)	103.21 (up)	103.21 (up)	84.05 (down)	109.64 (up)	108.75 (up)	109.64 (up)
AXAF (COP) Viewing Angle (deg)	84.05 (down)	76.57 (down)	64.41 (down)	108.75 (up)	80.79 (down)	90.00 (down)	90.00 (down)
Maximum Geocentric Angle for Mutual Visibility (deg)	38.39	31.96	41.80	38.39	48.23	37.50	39.27
Maximum Range (km)	4510.18	3719.09	5051.62	4510.18	5842.71	4397.63	4622.76

3.3.2.2 Test Range Requirement

A by-product of the process of examining the geometries and computing the viewing angles, is the maximum geocentric angle between these two platforms and hence the maximum range or distance between the platforms for each case. The greatest maximum range, 5842.71 km is for the case that the SSMB at 500 km altitude and AXAF at 1000 km altitude. The rounded-off value of 6000 km is used for link budget consideration.

3.3.2.3 Doppler Shift Compensation Requirement

Since both platforms are in relative motion constantly, the apparent frequency of a received signal at one platform is different from that of the original signal transmitted from the other platform. The frequency difference of transmitted signal and received signal is the so-called Doppler Shift.

The worst case Doppler shift is estimated as follows. Assume both platforms are at their lowest altitude of 276 km and 463 km, and their linear velocity are their maximum possible, 7.740×10^3 m/sec and 7.633×10^3 m/sec respectively. The largest Doppler shift occurs while these two platforms are moving along a straight line either head-on or receding from each other. The maximum fractional frequency shift is 0.005124%. For a signal with a carrier frequency of 60 GHz, the potential maximum frequency shift is ± 3.075 MHz. Doppler compensation has to be incorporated into system design, impacts of shift on frequency tracking, signal acquisition, and synchronization have to be considered.

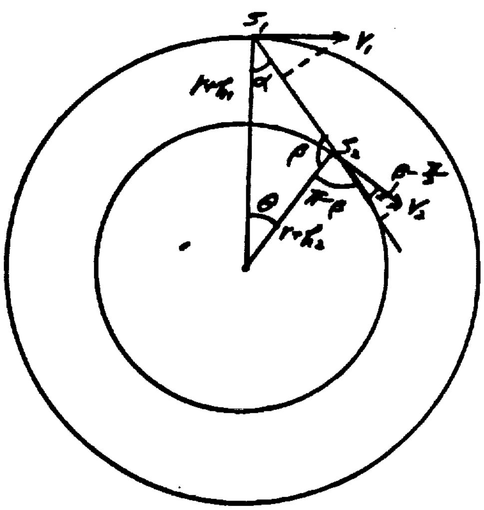
3.3.2.4 Antenna Slew Rate Requirements

An autotrack dish type antenna with two-axis gimbal drive is selected for the communications test set. Spaceborne autotrack antenna has been built and employed with some operational experience accumulated already. Because the experimental set will be deployed on two low earth orbit platforms, each moving with a high linear velocity about 7 km/sec, the antenna should be provided with a capability of higher slew rate to track each other and to cover the viewing angle defined in Section 3.3.2.1. The worst case of antenna slew rate is estimated as upper bound of the test system requirement. As indicated in Table 3.3-4, the slew rate requirement is very sensitive to the platform orbit, a slew rate of 11.80 degrees per second (omega_m) is required for the SSMB and AXAF at the nominal altitude of 463 and 500 km respectively and with a geocentric angle (θ_m) of 0.3091 degree. This slew rate requirement should be reevaluated before the design of the communication test set based on more detailed orbital information.

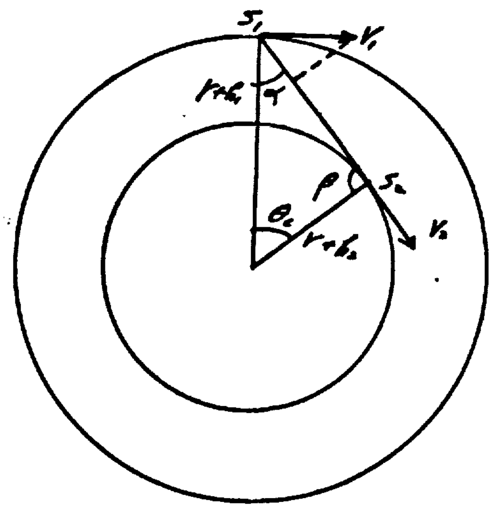
Table 3.3-4 Antenna Slew Rate Requirement (Upper Band)

SSMB Attitude (km)	**463**	**276**	**276**	**500**	**463**	**500**
AXAF (COP) Attitude (km)	**500**	**463**	**1000**	**1000**	**463**	**500**
SLEW RATE ω_o (deg/sec)	**0.0318**	**0.0326**	**0.0308**	**0.0301**		
SLEW RATE ω_m (deg/sec)	**11.80**	**2.355**	**0.5979**	**0.0578**	**0.0639** **(θ INDEPENDENT)**	**0.0634**
SLEW RATE ω_c (deg/sec)	**0.0634**	**0.0639**	**0.0571**	**0.0570**		
SLEW RATE ω_v (deg/sec)	**0.0636**	**0.0650**	**0.0599**	**0.0596**		

Two worst case geometries are shown in Figure 3.3-2, the first is that these two platforms are on the same orbital plane but at different altitudes with the geocentric separation angle varying continuously. The second is that these platforms not only are on the same orbital plane but also at the same altitude, however, the geocentric separation angle may assume any value. For the first case, there is a critical geocentric separation angle, θ_c for $0<\theta<\theta_c$, the slew rate omega increase as θ and reaches a maximum value omega$_m$ at θ_m. For the range $\theta_c<\theta<\theta_m$, the omega is a monotonic increasing function of θ; omega$_v$ is the maximum value of omega while θ assumes the maximum mutual visibility range. Figure 3.3-2 displays the geometries. The angle slew rate requirements are tabulated in Table 3.3-4. The highest maximum value is 11.80 degrees per second.



Case 1a



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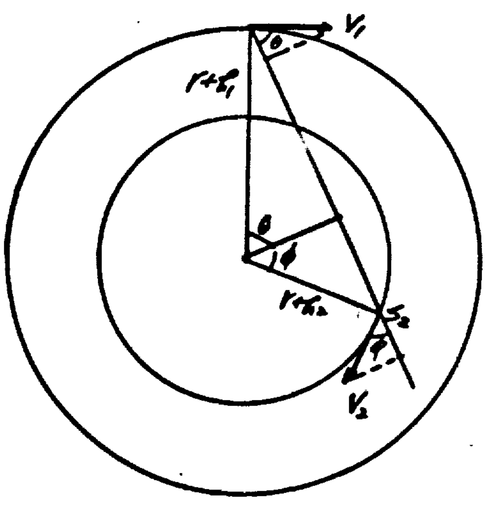
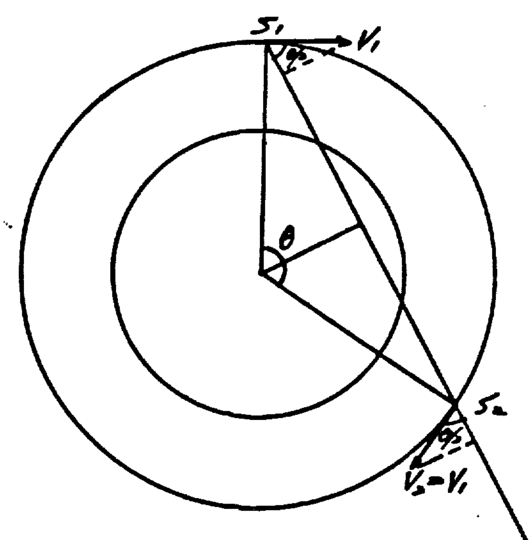


Case 1c



Case 2

Figure 3.3-2. Antenna Slew Geometry

3.3.2.5 TWTA Drive Requirement

The electric and radio frequency characteristics of the TWTA shown in Table 3.2-1 is assumed as a base for conceptual test system definition.

Due to the small test range to be covered for communication tests and the rated power of the TWT, a small antenna of 60 cm diameter meets the need. However, for evaluating the TWTA performance, observation of the tube aging characteristics, and linear and saturated operations of the TWTA, a TWTA driver with ample output power is needed.

Based on the 75 W output and 35 dB gain at saturation, the minimum required driving power is 23.7 mW. However, a 100 mW, 60 GHz driver is assumed for the purpose of circuit losses compensation and margin.

3.3.2.6 Cross-link Data Rates

The cross-link data rates selected for the test are 150 Mbps employing BPSK modulation and 300 Mbps employing QPSK modulation as discussed in Section 3.3.3 Communication System Experiment.

3.3.2.7 Cross-link Antenna Type and Size

The required antenna gain and size are the results of a compromising trade of several test system parameters as mentioned in the last section. The link budget of the system concept definition, Table 3.3-5 indicated an antenna with a gain of 48 dB. At this high frequency, a 60 cm (2 ft) solid reflector type antenna is adopted, because of its simple construction and weight. A Cassegrain antenna with five feed horns and generation and procession of antenna tracking signal have been employed in TDRS KSA antenna and LANDSAT. Some minor modifications will be incorporated into the final design based on experience gained.

Other antenna requirements; such as viewing angle (gimbal range) and slew rate, have been presented in Section 3.3.3.4 Antenna and Autotrack Subsystem.

3.3.3 Communications System Experiment Concept Definition

The major objectives of this proposed communications system experiment are to test some emerging technologies and newly available high frequency components along with the basic test of a high voltage power supply for a high power TWT operating at 60 GHz. This system test also offers the opportunity of evaluation of crosslink system design and operations. The 60 GHz communications system cannot be tested on the ground because of the oxygen-band attenuation. The following is a partial list of tests of opportunity in addition to the tests for the high voltage power supply.

1. TWTA space test, aging characteristics observation, and failure investigation
2. Onboard autotrack antenna system design and operation (acquisition, tracking, reacquisition)
3. Space tests of high frequency electronic components fabricated/constructed employing new device or material technologies:

<u>Components</u>
low noise preamplifier
attenuator
phase shifter
solid state amplifier
oscillator
mixer
downconverter
upconverter

<u>Technologies</u>
high electronic mobility transistors (HEMT)
heterojunction bipolar transistors (HBT)
metal semiconductor field effect transistor (MESFET)
monolithic microwave integrated circuit (MMIC)
improved interconnection and packaging
hermetically integrated microwave assembly (IMA)

TRW has a number of on-going IR&D programs not only investigating these technologies but fabricating devices for demonstration and test.

The incorporation of qualified new devices into the test system will accelerate these developments and enhance satellite communications system in one or more of the following area of interests, lightweight, small size, less power demand, high reliability, high data throughput, and low-cost.

However, to ensure the success of the experiment, some tested and proven components of current technologies are employed to the extent possible as discussed in the following sections.

3.3.3.1 Experiment Communication System

The defined experiment system is shown in a simplified block diagram in Figure 3.3-3. It is a 60 GHz intersatellite communications system for system performance and component testing and evaluation.

A random digit stream is generated by a processor, modulated on a carrier, upconverted, amplified by the 60 GHz TWTA package and transmitted to the terminal onboard the AXAF. The received signal is downconverted, demodulated into a baseband digital stream. The data stream is returned to the terminal onboard the SSMB through a similar process but in a reversed order on a carrier with a slightly different frequency. The detected returned-digital stream is compared with the original one for bit-error-rate determination. Provision is made that a pre-operational demonstration of communications can be made by introducing real data or messages in either one or both terminals for one-way or two-way communications test. Currently there is no direct communications link requirement between the AXAF and SSMB, however, if the demonstration is successful then an alternative communications path for the AXAF will be available for practical use.

The TWT and HVPS form a package of integrated TWTA. This package is provided with enough instrumentation, telemetry sensing devices and command actuators such that the system test Option No. 2 can be carried out periodically and independently on a time sharing basis with the communications system test. (See Section 3.3.4)

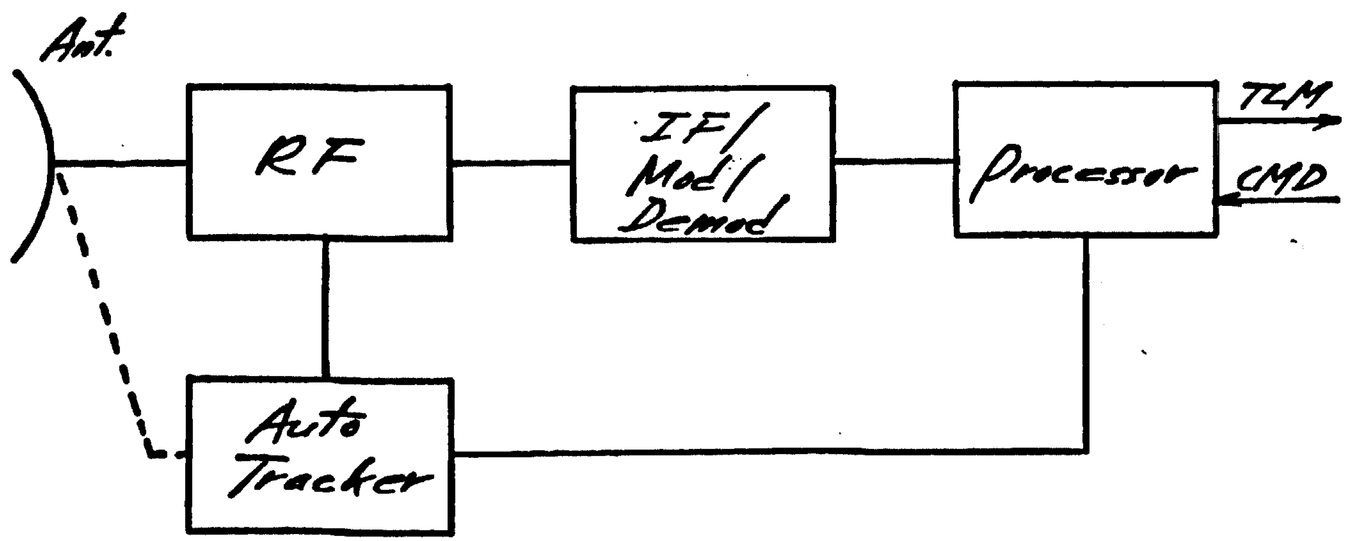


Figure 3.3-3. Simplified Block Diagram

3.3.3.2 Experimental System Link Budget

A system link power budget has been prepared and is summarized in Table 3.3-6.. The following guidelines are assumed for the link analysis.

1. 150 Mbps or 300 Mbps test data rate
2. BPSK and QPSK modulation format
3. Standard codes recommended by CCSDS as a test option pending availability of VLSI encoder/decoder chips
4. Data or parameter values based on TRW experience or IR&D project results.

These rates and modulation formats are current state-of-the-art adopted for ensuring the successful cross-link system testing. The emphasis of this testing has been placed on new high frequency components and materials technologies, cooperative antenna tracking and control, signal acquisition and synchronization in addition to high power and high frequency TWT and its high voltage power supply.

Table 3.3-5. Experimental System Link Budget

ITEM	SSF TO AXAF	AXAF TO SSF
FREQUENCY (GH)	60.0	63.0
XMTR POWER (DB) (75 WATT)	18.75	18.75
DIPLEXER/FILTER/CIRCUIT LOSS (DB)	-3.0	-3.0
ANT GAIN (60 CM DIAM, 45% EFF)(DB)	48.1	48.5
POINTING LOSS (DB)	-1.0	-1.0
SPACE LOSS 6000 KM MAX RANGE (DB)	-203.6	-204.0
CARRIER LEVEL (DBW)	**-140.75**	**-140.75**
ANT GAIN (60 CM DIAM,45% EFF) (DB)	48.1	48.5
POINTING LOSS (DB)	-1.0	-1.0
DIPLEXER/FILTER/CIRCUIT LOSS (DB)	-3.0	-3.0
ANTENNA NOISE TEMP (DEG K)	10.0	10.0
LNA NOISE FIGURE (6.5 DB GAIN) (DB)	4.5	4.5
RCVR NOISE FIGURE (DB)	6.5	6.5
RCVR SYSTEM NOISE TEMP (DEG k)	860.0	1040.0
RCVR G/T RATIO (DB/DEG K)	**14.76**	**14.33**
BOLTZMANN CONSTANT (DB/DEG K)	-228.6	-228.6
MODEM LOSS (DB)	-2.0	-2.0
DATA RATE (150/300 MBPS) (DB-HZ)	84.77	84.77
AVAILABLE E_b/N_o (DB)	15.84	15.41
REQUIRED E_b/N_o (DB) (10^{-6} BER BPSK/QPSK)	11.20	12.20
SYSTEM MARGIN (DB)	**4.64**	**4.21**

Some high data rates could be selected, however, this will result in a larger antenna with higher gain and narrower beam width. These will in turn impact antenna pointing and tracking, and signal acquisition and synchronization which are needed capabilities to be tested and demonstrated in this test opportunity. The selected data rates are the result of a trade and iterated system design addressing particularly the antenna size and control gimbal requirements and dynamic of the platforms.

3.3.3.3 RF Subsystem Hardware

An expanded block diagram including antenna and autotrack subsystem is shown in Figure 3.3-4. The RF subsystem components can be grouped into three categories as follows:

1. Group No. 1 traveling wave tube (TWT) and high voltage power supply (HVPS).
2. Group No. 2 diplexer, band pass filter (BPF), and direction coupler
3. Group No. 3, low noise amplifier (LNA), upconverter and downconverter (including local oscillator or frequency multiplier, mixer and amplifier)

The TWT provided by another contractor and HVPS are assembled in an integrated package with necessary instrumentation for testing and measuring their characteristics and performance (See Section 3.3.4).

The components of Group No. 2 included lower frequency components with their principles and practice of design and fabrication well known; and have been flown many years.

As for the components of Group No. 3, it is recommended that new emerging technologies be employed for their design and fabrication. Some maturing material, devices, package technologies have been listed in Section 3.3.3. TRW presently conducts a dozen or more related IR&D programs; their results of developments could be incorporated into this experimental communication system for space test.

The following are a few examples:

1. MMIC LNA employing MESFET, 2 stage, 7 dB gain, 6 dB noise figure
2. HMT LNA
3. HMT Mixer with microstrip lines for signal input and output
4. HBT oscillator and amplifier

The above devises are operating at 60 GHz, and some devices and components operating on 20/44 GHz bands, 92-98 GHz bands, etc. are also under development.

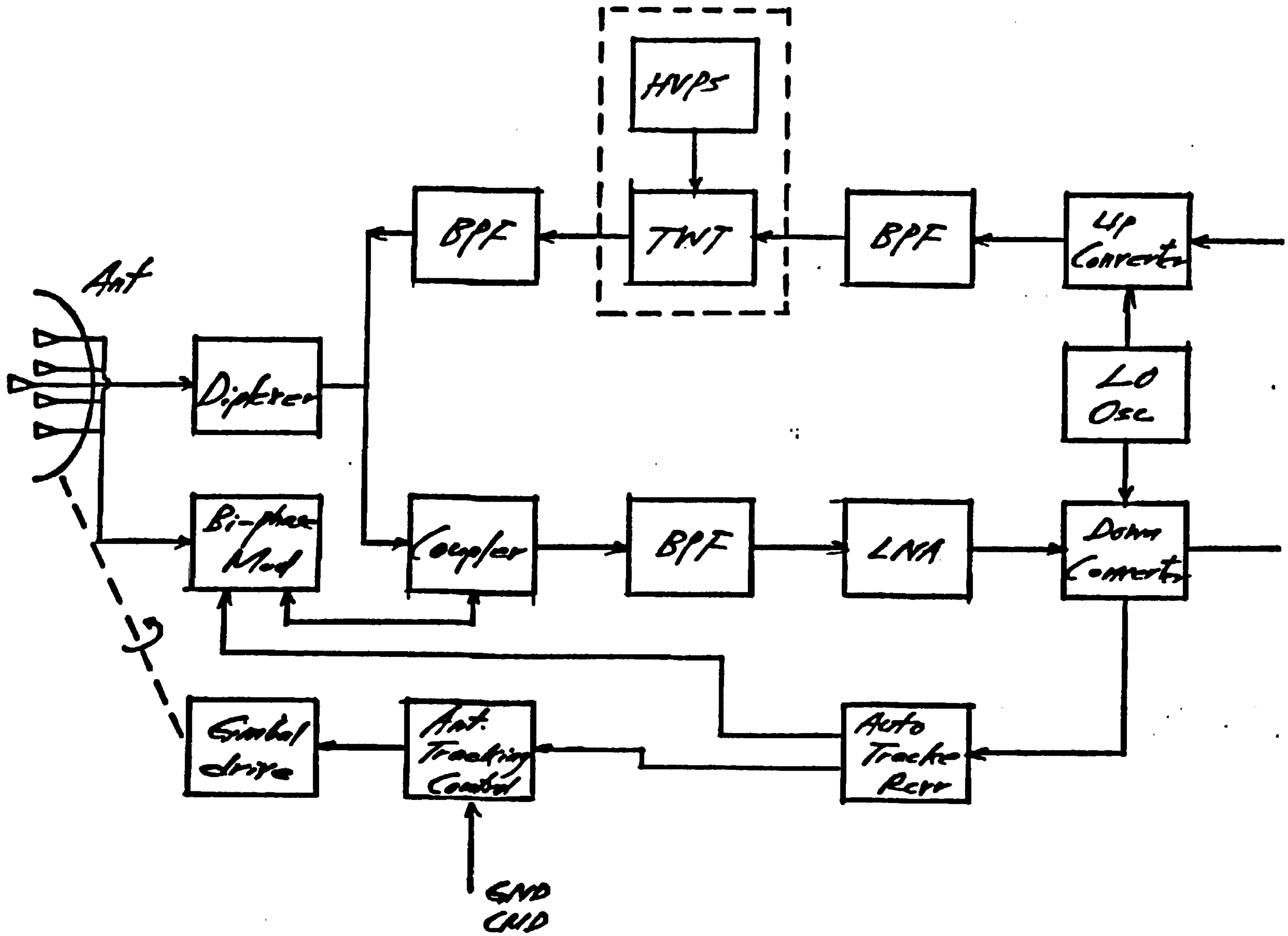


Figure 3.3-4. RF Subsystem Block Diagram

3.3.3.4 Antenna and Autotrack Subsystem

The selected antenna is a conventional Cassergrain design with a 60 cm (24 in) diameter solid reflector made of graphite epoxy. This antenna provides a half-power beam width of 0.62 degrees and a gain of 46.4 dB, assuming 50% antenna efficiency at 60 GHz. Note that a larger antenna with higher gain at this frequency can be designed and built for spaceborne use but in view of the large carrier power available (75 Watt RF TWT) and the short range (6000 km) to be covered, a 60 cm reflector is selected to relax antenna mounting, autotracking, and weight problems. This small antenna in conjunction with the powerful TWTA provides more than enough carrier-to-noise ratio at the receiving end (See Section 3.3.3.2).

The five horn monopulse feed of current LANDSAT and TDRS KSA antenna design is adopted to generate antenna pointing error signals. A microprocessor based antenna control processor performs all computation necessary to convert the error signals to antenna pointing commands for gimbal drive. This proven design and the wider beam width (0.62 degrees as compared with 0.28 degrees of TDRS KSA antenna) assures the success of antenna pointing and tracking.

All critical components including diplexer, directional coupler, autotrack, comparator and two-phase modulator are enclosed in a separated housing that is mounted directly behind the feed. Only one waveguide is to be brought across the gimbal.

TRW is currently developing a beam wave guide (BWG) antenna for high frequency use in an IR&D project. The BWG replaces the normal wave guide bends and rotary joints and not only eliminates losses but also makes orthogonal mode operations possible. This BWG antenna is also a candidate of opportunity of test.

3.3.3.5 IF, Modulator and Demodulator Subsystem

Figure 3.3-5 displays the intermediate frequency, modulator and demodulator subsystem. Both BPSK and QPSK modulations are provided. Conventional, proven and currently available components are recommended for this subsystem to further reduce the experimental system risk.

The encoder and decoder set enclosed in the dash-line blocks are optional. VLSI chips for Reed-Solomon encoder/decoder and convolutional encoder/Viteri decoder meeting standard codes recommended by Consultative Committee for Space Data System (CCSDS) are currently under development and supported by NASA. These chips would be available for incorporation into the experimental system. Other potential sources of component are current TRW IR&D projects of formatting and multiplexing equipment (FAME) and breadboard upgrade and data management system (DMS).

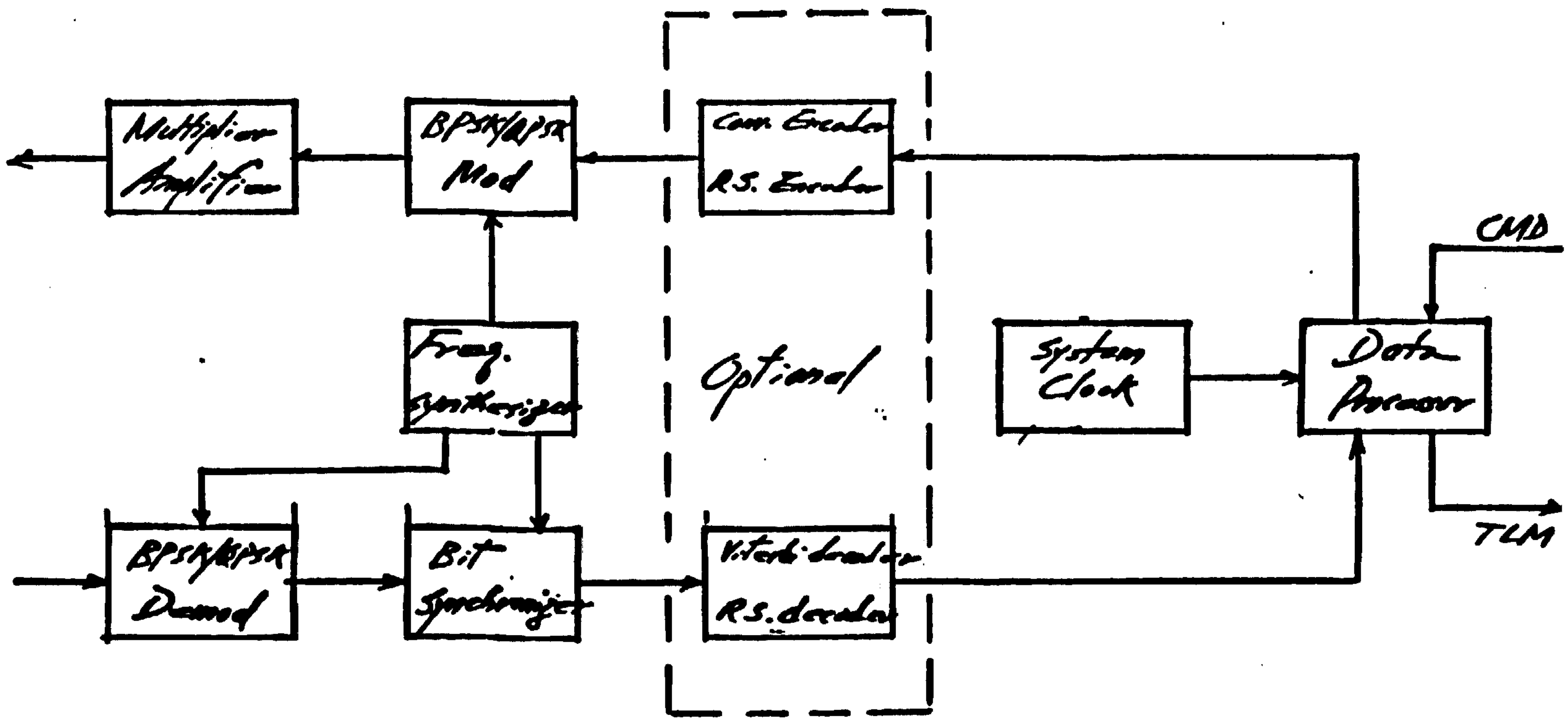


Figure 3.3-5. IF, Modulator and Demodulator Subsystem

3.3.3.6 Data Processor and Power Supply

A microprocessor-based data processor is to provide all experimental data processing needs and control the communication system.

The major functions are

1. Generate quasi-random digital data stream for transmission, compare transmitted and return data streams, and determine transmission quality
2. Schedule and conduct preplanned tests
3. Receive, process and execute commands originated from ground
4. Collect, process and format telemetry for transmission
5. Provide internal interfaces of experimental communications system and external interface with the data management system (DMS) of space station through the data processor of the high voltage power supply test facility.

The data link processor is a stand alone design which supports all telemetry and command needs for the communication package including antenna command and control. An identical package including communication package, is proposed for both SSMB and AXAF terminals. The only differences is that the incoming commands and outgoing telemetry data bus interfaces with APAE of SSMB through the command and data processor of the HVPS Test Facility for the SSMB terminal and interface with the TTC subsystem of AXAF for the AXAF cross-link terminal.

The estimated TLM rate is about one kbps and the CMD rate is about two kbps. Therefore, time sharing with SSMB and AXAF TTC link is recommended.

A power supply and distribution subsystem as shown in Figure 3.3-2 is to obtain primary power from the space station APAE prime power and to provide all power needs of the experimental communication system. Voltage and current monitoring and emergency shut-off capability are also provided.

3.3.4 TWTA Test

This is the Option No. 2 TWTA test presented in the experimental option trade previously. The TWTA test is recommended as a fall-back option if for any reason the communication system test cannot be carried out.

This option takes the advantage of available HVPS and TWT to conduct an integrated TWT/HVPS life test in a LEO environment and observation of TWT and HVPS deterioration with time and possible cause of failure.

The test set up is depicted in Figure 3.3-6. Major components needed in addition to the TWTA and HVPS are as follows:

1. 58-65 GHz oscillator and amplifier
2. Wideband modulator/driver with coarse and fine power adjustment and capable of single or dual frequency modulation
3. Dummy load and relay controlled switches
4. Waveguide plumbing
5. RF power measuring devices including directional couplers
6. VSWR metering for both input and output
7. Temperature sensing and thermal stat for heaters
8. Controlling relays and actuators
9. TLM/CMD circuits and data processing

A series of tests will be conducted according to a predetermined schedule; all tests will be initiated and controlled from the ground with generated data analyzed post-test. The following is a list of the tests:

1. Small signal gain versus frequency
2. Power output versus frequency with variable input power as parameter
3. Swept power test
4. Saturated power versus frequency
5. Efficiency measurements at various output power level and saturated power
6. Phase shift characteristics
7. Tube noise measurement
8. Product of gain and noise measurement
9. AM-to-PM conversion
10. Overall efficiency

Some tube operation parameters will be monitored continuously with digital read-out or analog signal transmitted to ground in specified time intervals through telemetry subsystem. The monitored parameters include at least the following:

1. Cathode voltage and current
2. Filament voltage and current
3. Body voltage and current
4. Anode voltage and current
5. Collector voltages and currents
6. RF power input and output
7. Input and output VSWR
8. Temperature at various points of TWTA
9. Positions of relays and actuators

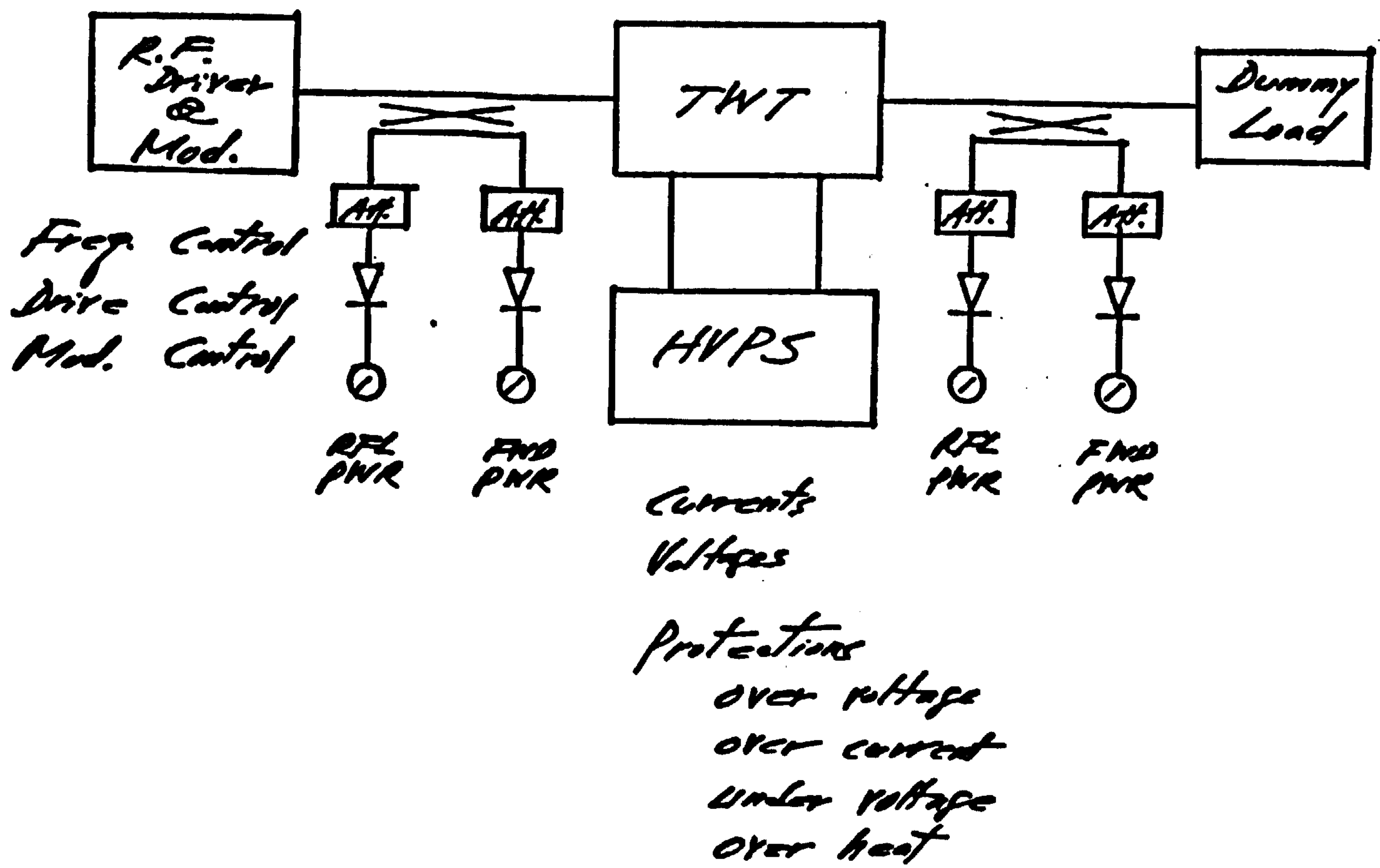


Figure 3.3-6. TWTA Test Setup and Major Instrumentation (Option 2)

3.3.5 Other Requirements

Location. The 60 cm diameter reflector antenna with its two-axis gimbal drive is to be located near the edge of SSMS truss, mounted on a multiple payload adaptor (MPA), payload interface adaptor (PIA), deck carrier assembly, through station interface adaptor (SIA), as one of several payloads. All of PIA, MPA and SIA are space station provided user support. A housing mounted behind the feed encloses some critical RF components. A separated transmitter/receiver front-end housing which contains the integrated TWTA and HVPS, IF, modulator, demodulator, and other components should be located as close to the antenna as possible. A waveguide runs between the antenna and the transmitter/receiver housing. No components of the experiment high loss of waveguide at this frequency, the distance between the antenna and transmitter and receiver should be minimized. No component of this experimental communication system is required to be located inside of habitation and command module.

Safety. Stray radiation from TWTA, HVPS, waveguide, waveguide switches and joints should be kept well within the SSMB environments requirements.

The antenna should be pointing away from the SSMB in order to eliminate possible RF hazard or interference with on-board electronics and instrumentation of other tests and experiments. Either physical stops or gimbal step command should be employed to prevent pointing the high gain antenna to any part of the SSMB. Furthermore, radiation level of sidelobes and backlobes of the antenna should be measured on ground and recorded for reference. The actual radiated power is under the processor control according to the distance between the SSMB and the other terminal such that the received radiation field is adequate for communication test but below the level to cause any interference or damage to electronics on the other platform.

Prior, during, and after docking operation, and during the period of EVA around the SSMB, the communication test can be interrupted by real-time ground commands or by sending commands in advance to the processor for execution.

Volume, Weight, and Power. A preliminary estimate of volume, weight and power requirement is tabulated in Table 3.3-7.

Table 3.3-7. Preliminary Estimate of Experimental System RF Components

ITEM	WEIGHT (LB.)	POWER (WATTS)	SIZE (INCHE.
ANTENNA ASSEMBLY			
ANTENNA	30		48X48X28
GIMBLE DRIVE	15	15	14X14X12
DRIVE ELECTRONICS	5	6	9X6X3
AUTOTRACK RCVR	2	4	6X3X2
FRONT END ELECTRONICS			
DIPLEXER	2		4X3X3
COUPLER	1		5X3X2
BPF	1		4X2X2
LNA	4	6	3X2X2
DOWN CONV.	2	3	3X2X2
BIPHASE MOD	2	3	3X2X2
RF ELECTRONICS			
BPF	4		4X2X2
TWT	15		20X6X6
HVPS	33	275	18X8X8.5
SSA	5	4	4X4X3
UP CONV	3	2	3X3X2
MOD/IF/DEMOD			
FREQ MULT/AMP	4	3	3X2X2
BPSK/QPSK MOD	5	3	5X4X2
DOWN CONV/IF	4	2	3X3X2
BPSK/QPSK DEMOD	4	3	5X4X2
BIT SYNCHRONIZER	5	6	8X4X2
CLOCK/POWER SUPPLY			
SYSTEM CLOCK	2	1	2X1X1
FREQ SYNTHERZIER	4	3	4X4X1
POWER SUPPLY	2	20	5X5X3
	---	---	
TOTAL	153	359	

3.4 Diagnostic Package

This experiment is to operate a high voltage system (at voltages to - 18 KV) using space vacuum as the primary means for insulation (see Figure 3.4-1). Since the experiment is to be vented into a space plasma environment, then the possibility of discharges induced by this particulate environment must be addressed. The purpose of this diagnostic package to discern any interactions between the experiment and plasma environments or discharges that may occur.

In the operation of the high voltage system, there are two possible mechanisms for inducing discharges: Paschen discharges due to increased pressure in the enclosure (due to outgassing of components or other possible sources) and plasma induced breakdowns. It is assumed that the package will have been tested adequately prior to launch to preclude Paschen discharges due to component outgassing in high electric field regions.

At Space Station altitudes, the resident thermal plasma density can be as high as $10^6 cm^{-3}$. At these densities, discharges can be induced by bombarding the high voltage surfaces with plasma particles. The plasma density in the experiment volume can be increased by the ionization of outgassing molecules (which have about 10 eV ionization potentials) by the large electric fields generated in the experiment. Even though there currently is uncertainty in the orbit that will be used for this experiment, the diagnostic package has been designed primarily for Space Station operation.

3.4.1 Diagnostic Package Description

The diagnostic package includes the following measurements:

- TWT body/helix current
- Plasma Probes -- external and internal
- Screen baffle plate detector
- Arc transient monitor
- Contamination monitor
- TQCM -- 4 places
- Temperature

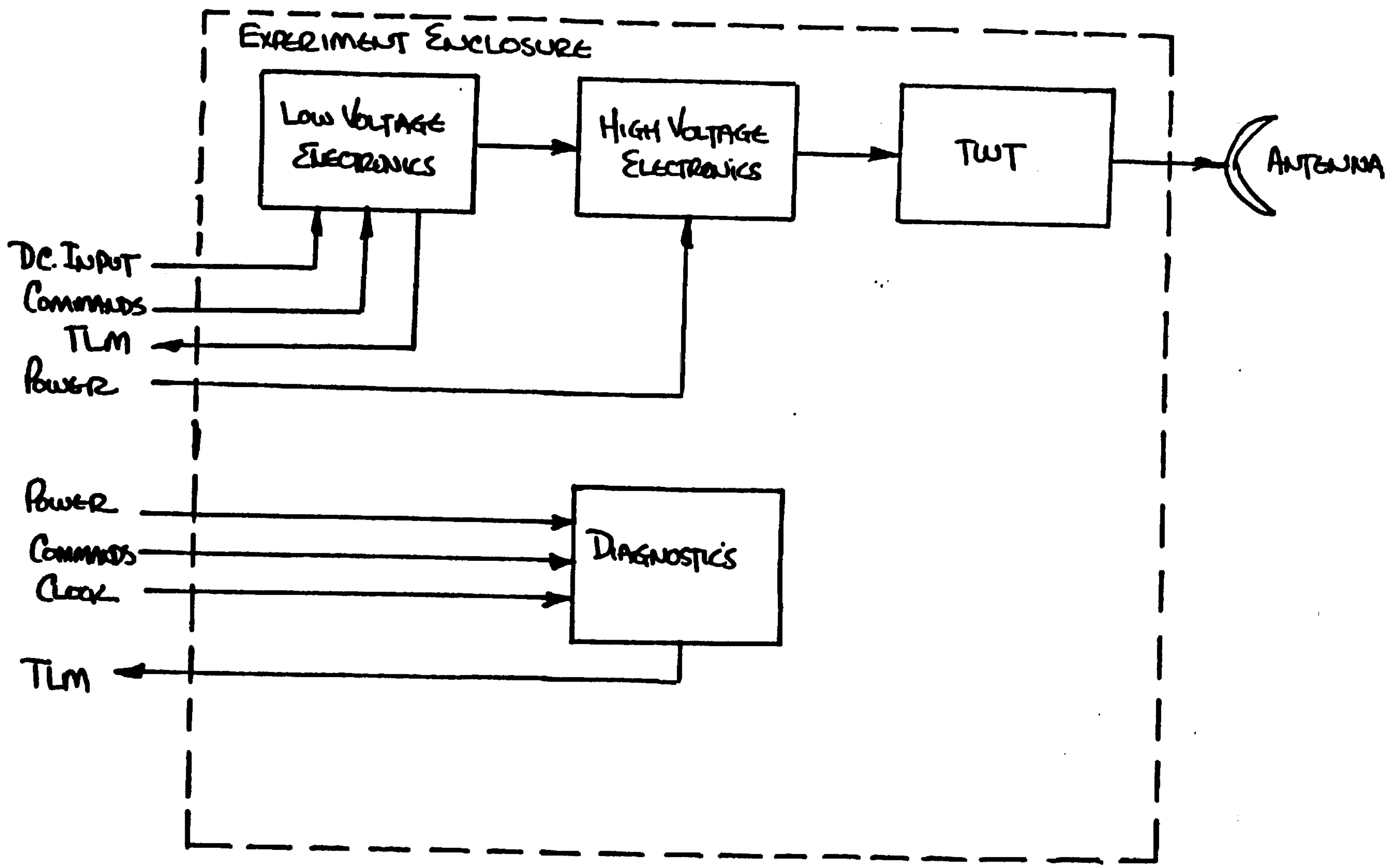


Figure 3.4-1. High Voltage Power Supply Experiment Block Diagram

No detection devices are contained in the HVPS except for the TWT body/helix current measurement. The HVPS is an extremely complex mechanical assembly and the inclusion of any sensors in the HVPS would interfere with the internal high voltage electric fields. A video camera was evaluated as a means of monitoring internal arcs if there were a transparent side on the HVPS, but this would change the actual electric fields and possibly cause a change in the thermal control of the high voltage components. The complete diagnostic package is identified in Table 3.4-1 along with a weight, power requirement and cost summary. The suggested locations for the instruments are shown in Figure 3.4-2. The command and telemetry requirements are given in Table 3.4-2. The following sections briefly discusses the design details of the proposed measurement instrumentation.

3.4.1.1 TWT Body/Helix Current

A key reading in laboratory tests of these high voltage packages is the TWT body/helix return currents. This reading is used to indicate discharges in the system. This reading should be repeated in the flight experiment. All that is required here is to insert an ammeter in the ground return line. The meter should measure currents from zero to 10 mA.

3.4.1.2 Pressure Measurements

The next instrument to be included in the package is a pressure gauge. This instrument monitors the pressure in the outside enclosure and should be mounted as close to the operating electronics as possible without jeopardizing the high voltage system operations.

In Shuttle flights the pressure was measured, in the bay, at about 10^{-7} torr after a few days. This pressure was about the expected ambient for the 240 km altitude of the Shuttle. A variation was measured from 10^{-5} to 10^{-7} torr due to gas ramming into the Shuttle bay.

For the purposes of this experiment, an ion gauge pressure measurement will be acceptable. This device can measure over the range of 10^{-3} to 10^{-7} torr. This will allow monitoring of any change in pressure between the initial start of the experiment and after the conclusion of a run. The pressure gauge may have to be turned off during the high voltage operation due to possible plasma interaction with the high voltage electronics. This can be determined in the ground test of the facility.

The neutral gas pressure will be monitored in the facility enclosure prior to initiation of the high voltage experiment. Any increase in pressure obtained while the experiment operates can be determined by the post test readings if the continuous operation of the gauge is found to disrupt the high voltage system. If discharges do occur, then the pressure range for breakdowns can be obtained. If there are no discharges, then the safe operating pressures will be defined.

Table 3.4-1. Instrumentation for Diagnostic Package

INSTRUMENT	SOURCE	PURPOSE	INPUT REQUIRED VOLT	INPUT REQUIRED POWER	WEIGHT LBS
AMMETER		TWT BODY RETURN CURRENT			
ION GAUGE	PERKIN ELMER	MONITOR ENCLOSURE PRESSURE	0-200VDC	4	
LANGMUIR PROBE SYSTEM	TRW	MONITOR PLASMA DENSITY	28VDC		
AMMETER - VOLTMETER		BIASED PLATE PLASMA MEASUREMENTS			
TRANSIENT MONITOR	TRW	COUNT/CHARACTERIZE DISCHARGE TRANSIENTS	28 VDC	3	3
TQCM	OCM RESEARCH	MONITOR CONTAMINATION	28 VDC	60	6

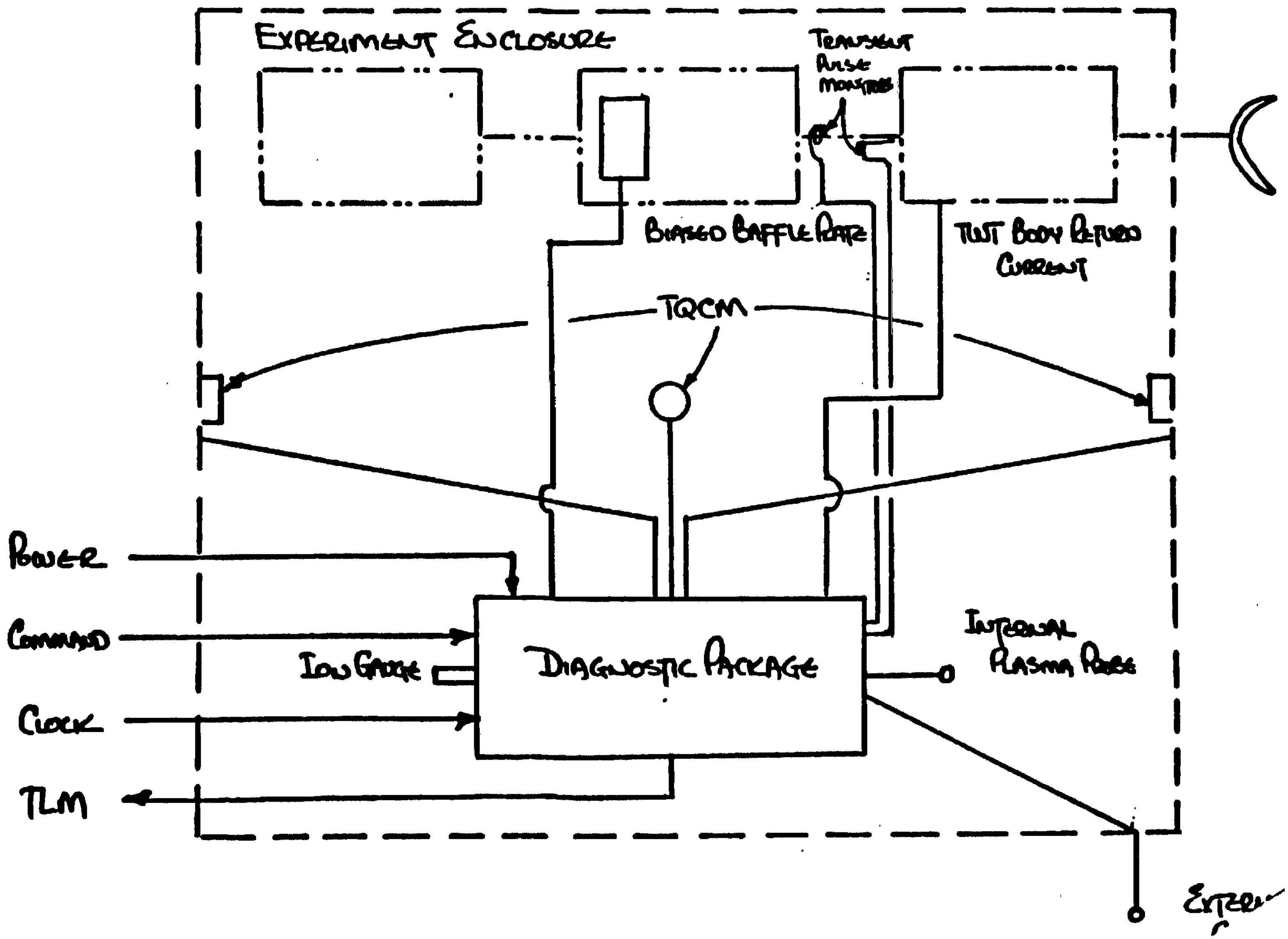


Figure 3.4-2. Location of Diagnostic Instruments

Table 3.4-2. Command and Telemetry Requirements - Diagnostic Package

Instrument	Command	Telemetry
Body Current Ammeter	on/off	Reading 0 to 10 ma - Analog
Pressure Gauge	on/off	Reading 10E-4 to 10E-7 Torr - Analog
Plasma Probe - outside	on/off	* Current 10E-6 to 10 E-8 amp - Analog
Plasma Probe - Inside	on/off	* Current 10E-6 to 10 E-8 amp - Analog
Bias Baffle Plate	Pos. A	Voltage - Analog
	Pos. B	Current 10E-6 to 10E-8 amp - Analog
Transient Monitor	on/off	** - Digital Number Pulses Positive Number Pulses Negative Peak Voltage - Analog Peak Current - Analog
TQCM	on/off	Frequency 8 bit - Digital
	temp 1	0 to 10 VDC - Analog
	temp 2	Temperature Reading - Analog
	temp 3	Temperature Reading - Analog
	temp 4	Temperature Reading - Analog
		Heat Sink Output - Analog

Notes:
* Probe reading taken only during probe sweep rate of 1 per sec for 80 seconds for sweep. Want simultaneous probe reading inside and outside

** Transients to be counted for given time interval - usually one second.

The gauge works by establishing a potential difference between an ion filament and an electron filament. Electrons ejected from the filament migrate toward the positive ion filament and collide with the molecules present between the filaments, ionizing molecules of the gas. The pressure can be determined by measurement of the ion filament current. The specifications for a typical Bayard-Alpert ion gauge is given in Table 3.4-3. The ion filament current can be directly related, through ground calibration for a given grid voltage, to determine the species number density of the environment and its composition.

In association with the pressure measurement, it is necessary to monitor component temperatures. These temperatures should be taken at or within the electronics boxes if possible without jeopardizing system operations. Thermistors can be used to make these measurements.

Table 3.4-3. Ion Gauge Characteristics

General	
Application	Pressure Measurement, Total and Partial
Vendor	Balzers, Perkin-Elmer, Esterline
Model	Nude Filament
Cost	$1,000 +/-25%
Range	10E-3 to 10E-7 Torr
Response	0.1 msec
Mass	1800 grams
Volume	50 cc
Life	Long
Calibration	Pre-Flight
Technology Requirement	Moderate
Instrument Inputs	
Voltage	0 to 200 VDC
Current	3 amps peak
Instrument Outputs	
Current	10E-4 to 10E-7 amps

3.4.1.3 Plasma Density Measurements

Plasma density measurements will be made both outside and inside of the experiment enclosure. The basic devise for monitoring the plasma density on this experiment will be a spherical Langmuir probe. This device has been used in the past to make these measurements in orbits similar to the one in this experiment.

The operation of the probe is straight forward. A metallic sphere, about 1/2 inch on diameter, is mounted on a dielectric rod and inserted in the plasma. For this experiment the probe does not have to be deployed and can be mounted directly in its measuring position. This sphere is biased over a range of voltages (-30 to +30 volts) in preset voltage steps (2 volts). The current collected by this sphere is monitored as a function of this bias voltage. Both positive and negative bias voltages are used to obtain a characteristic similar to that shown in Figure 3.4-3A for the expected plasma density at Space Station (about 2 X 10^5 cm^{-3}). This data can be used to obtain the plasma density, particle characteristic energy and ion specie. The effect of a change in the density is determined from the electron current collection region of the data. As shown in Figure 3.4-3B, this change can be readily obtained. The characteristic energy is obtained from the initial slope of the data. The ion specie can be found from the ion collection probe data (see Figure 3.4-3C). As shown it will be possible to distinguish between protons, oxygen ions and any heavier ionized outgassing contaminant.

There will be a probe inside the experiment enclosure and one outside (see Figure 3.4-2). The concept is to use both probes to discern whether or not there is a plasma density increase due to ionization of outgassing constituents within the experiment enclosure. Typical instrument characteristics are given in Table 3.4-4.

If there are discharges, then the probe will be used to define the threshold density for the onset of breakdowns. If there are no discharges, then the instrument will define the safe operating range for high voltage operations.

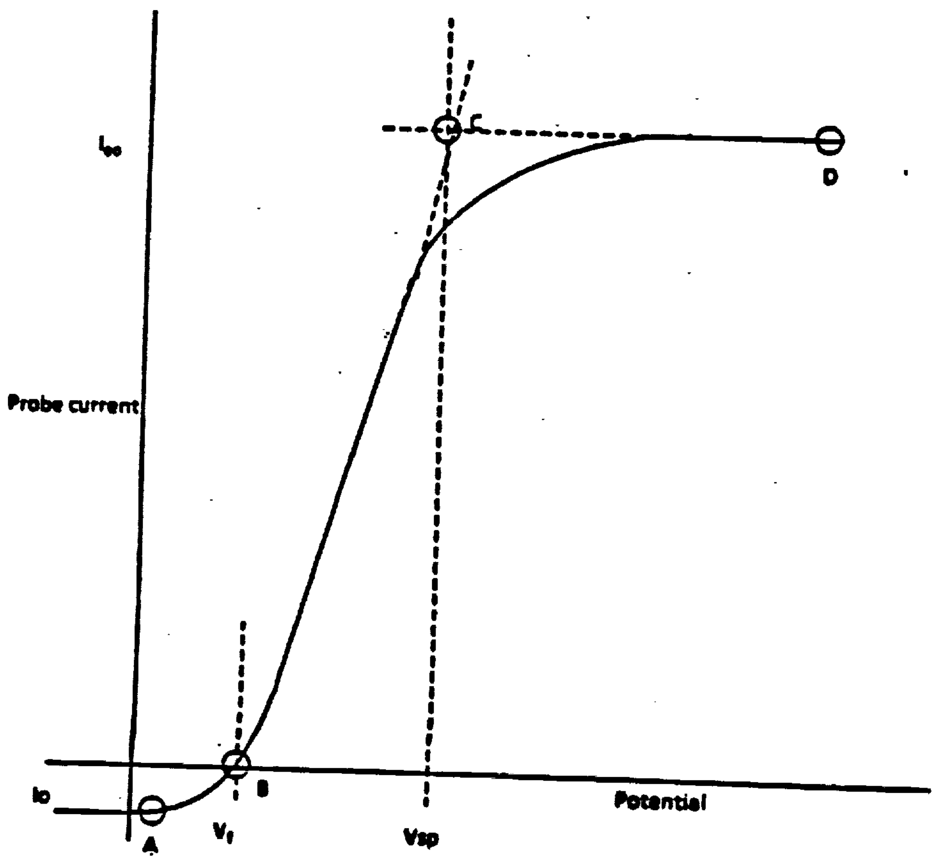


Figure 3.4-3A. Langmuir Probe Characteristics

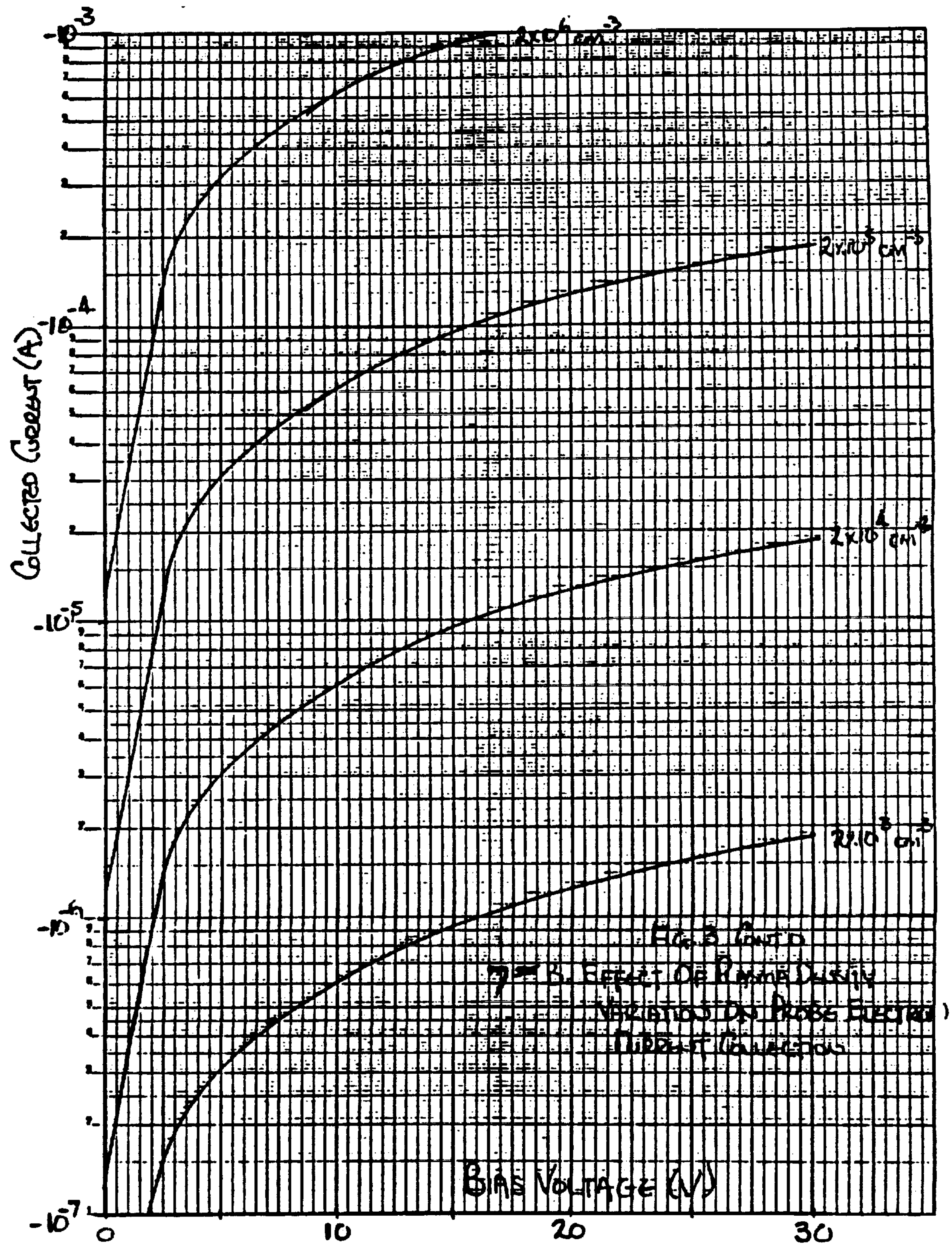


Figure 3.4-3B. Langmuir Probe Characteristics

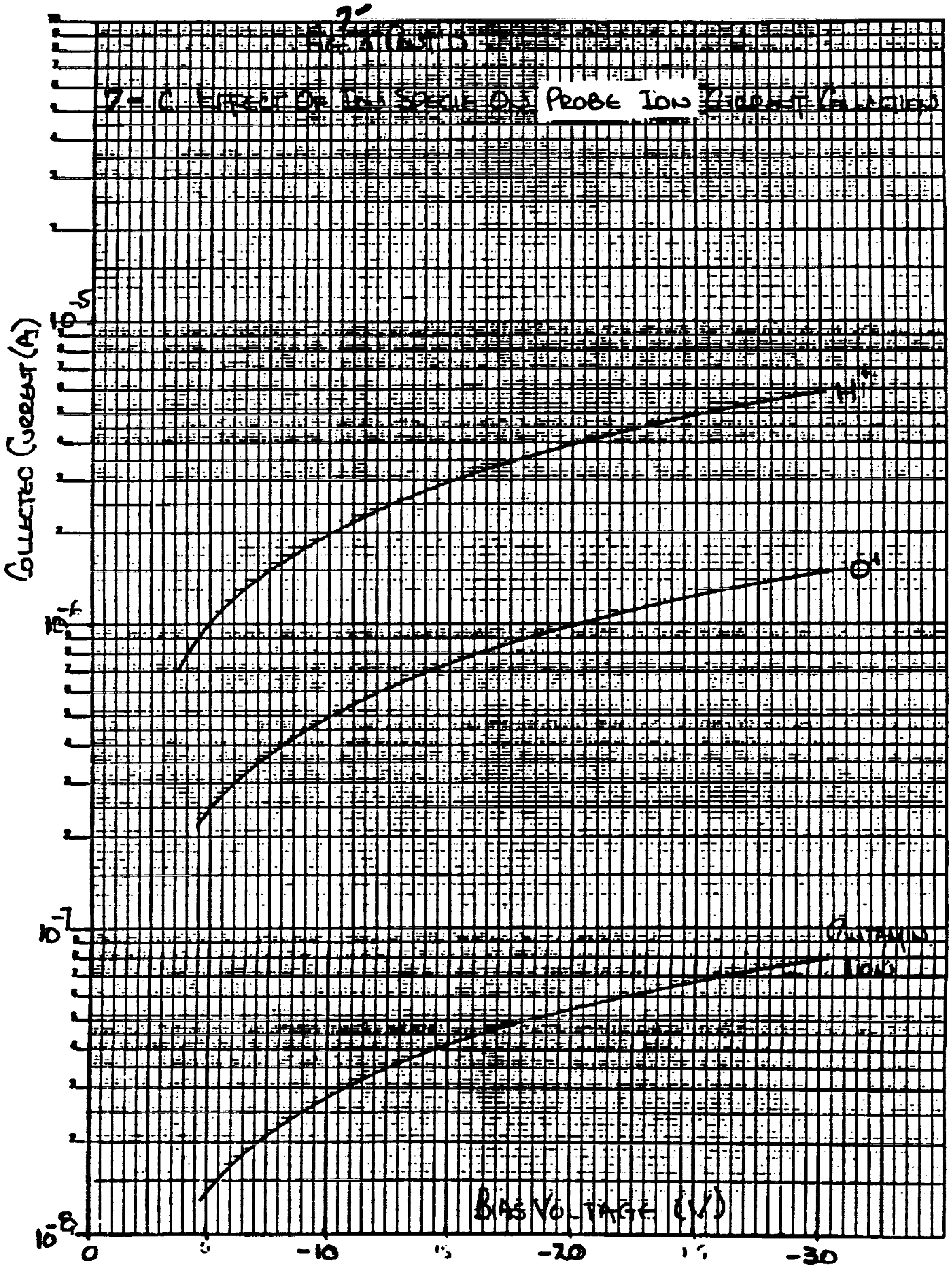


Figure 3.4-3C. Langmuir Probe Characteristics

Table 3.4-4. Langmuir Probe System Characteristics

General	
Application	Plasma parameter and spacecraft charging measurements
Vendor	Prime Contractor
Model	Spherical and cylindrical
Cost	$25,000 +/-25%
Output	Probe Current and potential
Mass	< 1200 grams
Volume	< 1800 cc
Technology Requirement	Moderate
Instrument Inputs	
Voltage	+/- 10 and +/- 50 VAC
Instrument Outputs	
Current	10E-9 to 10E-4 amps

3.4.1.4 Biased Baffle Plate

The outgassing vents on the high voltage electronic compartment are covered with an offset baffle plate. This is to prevent any unwanted flow into the high voltage compartment. For this experiment, the plate on the top of the compartment will be mounted on insulating standoff and the plate will be used as a diagnostic tool. This plate will be switchable (see Figure 3.4-4) so that it can measure its voltage relative to the compartment or a collected current. This measurement will be used to verify that the screens do constrain the 18 KV fields within the compartment. If the vents actually are porous to the electric fields, then a current will be induced on the plate.

The plate will also have the capability of being switched to a small bias power supply that will apply -20 volts to the plate. For an electrically well confined container, this voltage should be adequate to trap any space environment or ionized outgassing ions. The current reading from this plate can be used as a plasma detector. If there are any increases in the current that are not correlated to the other plasma probe readings, then it must be assumed that the high voltage system is changing the local plasma density.

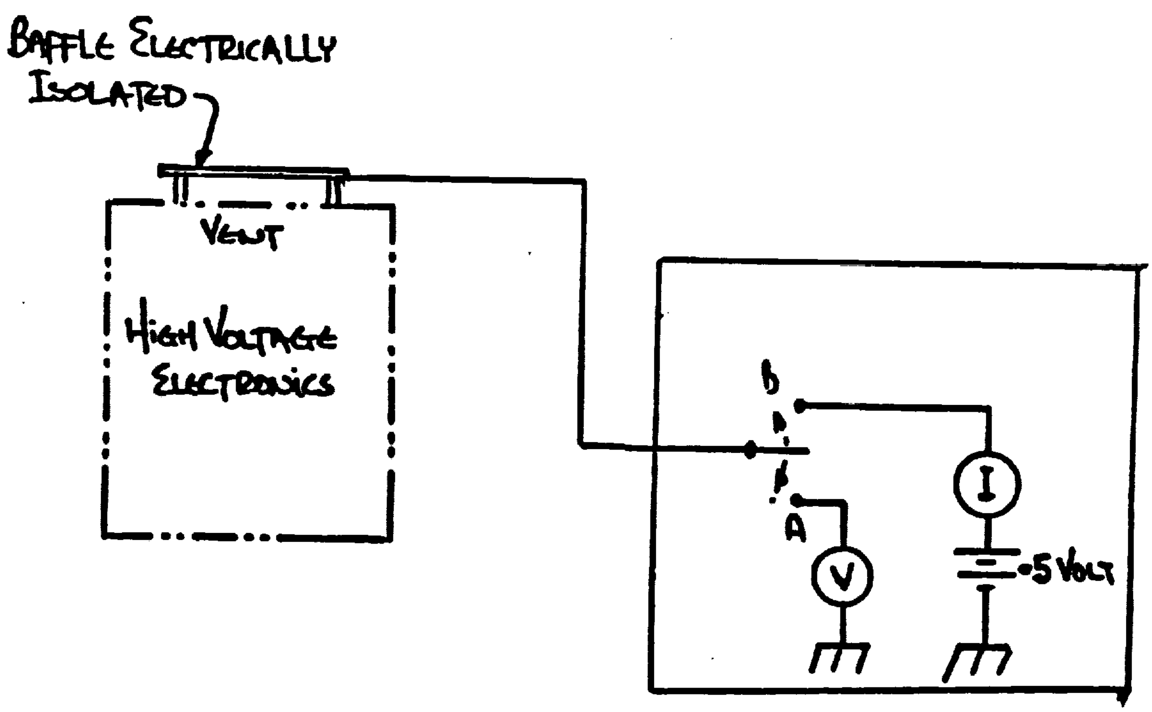


Figure 3.4-4 Biased Baffle Plate Experiment

3.4.1.5 Transient Monitors

If there are discharges, then the characteristics of the transient induced should be monitored. This will be done by use of a counter and voltage and current probes on the power lines. This technique will not allow direct measurement of the discharge, but will provide the coupling effect of the pulse. Such instruments have flown before and provided usable results.

The technique will be to use a line detector attached to the harness to count the number of pulses, both positive and negative, that occur in the line. In order to prevent counting line ringing as multiple discharges, the counter will be disabled after detecting a transient for a period of time necessary to allow the line to ring down. This down-time period will be determined from ground tests. For the CTS Transient Monitor, the counter was off 10 microseconds and this device functioned very well. The discharge voltage and current transient will be measured as the peak value that occurs in this pulse. While this will not completely characterize the transient, it will categorize them.

The monitors are shown pictorially in Figure 3.4-2. The devices will detect transient currents by means of a current loop sensor around the wire and voltage transients by means of an antenna strapped to the harness. The response of these instruments will be calibrated so that command and power transients will be ignored while the discharge transients will be monitored.

3.4.1.6 Contamination Monitors

One concern is the effect of long time deposition on breakdown characteristics in the electronics. This will be monitored by use of temperature controlled quartz crystal microbalances (TQCM). These devices can be set to collect contaminants at a controllable temperature.

The TQCM consists of sensor heads and electronics body. The usual arrangement is to have four sensors controlled by a single electronics unit. In the sensor, there are two polished quartz crystals, one exposed to the environment while the second is protected. The crystals oscillate relative to each other with a beat frequency that is a function of the mass of the crystal. As the outer crystal becomes contaminated, the beat frequency of the two crystals will increase. The mass on the outer crystal can be determined based on the sensitivity of the crystal. The temperature of the crystal is controlled from -60^0 to $+80^0$ C by means of Peltier thermoelectric systems. The operation at cold temperatures enhances deposition because most of the contaminants stick to the crystal. The contaminants can be driven off by heating the crystal. If the heating is controlled, then it is possible to determine the characteristics of the contaminants by determining the mass loss as a function of the crystal temperature by utilizing the partial pressure of the contaminant to identify it.

A schematic of the TQCM system is shown in Figure 3.4-5. The suggested locations of the sensors is shown in Figure 3.4-2. The concept is to have at least one sensor outside the enclosure to be able to discern the changes in the ambient as opposed to the changes within the enclosure. The specifications for these systems are given in Table 3.4-5.

Table 3.4-5. TQCM Characteristics

General	
Application	Precise Measurement of Surface Deposition
Vendor	Faraday Labs, QCM Research
Model	10 to 15 MHz crystals
Cost	$75,000 +/-25% including electronics
Output	0 to 100 kHz beat frequency
Range	</=100 kHz (<=200 micro grams per sq cm)
Response	1 sec
Mass	600 grams
Volume	500 cc
Life	4 + years
Calibration	Pre-Flight Only
Technology Requirement	Moderate
Instrument Inputs	
Voltage	28 VDC
Current	2 amps peak
Power	15 w peak, 2 w continuous
Instrument Outputs	
Voltage	0 to 10 VDC (optional)
Frequency	0 to 100 kHz beat frequency
Digital	8 bit digital word

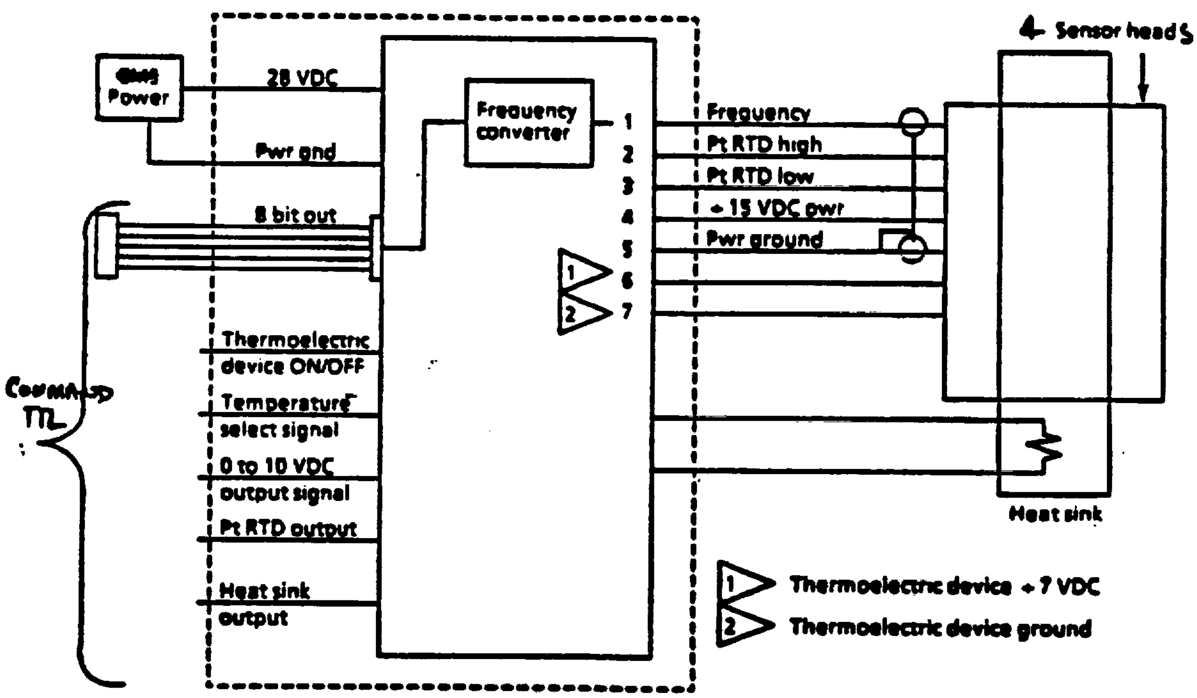


Figure 3.4-5. TQCM Schematic

3.4.2 Ground Testing

It is recommended that this package be subjected to a comprehensive ground test program. This would enhance the output of the program. In a ground test, the flight instruments can be calibrated against an extensive array of additional instruments that are not practical to fly. For example, a mass spectrometer can be employed in ground tests to characterize the outgassing components from operating the experiment. This information will be the same as would be found in space. The electromagnetic interference resulting from any discharges can be characterized on the ground much better than in space. Both of these areas can be measured in ground tests and the flight instruments can be calibrated to recognize their characteristics.

3.5 Command and Data Processor

The objective of the command and data processor is to :

- o Start, operate and monitor the High Voltage Power Supply
- o Operate and monitor the 60 GHz communications experiment
- o Operate and monitor the diagnostics package
- o Store, format and send the HVPS test facility experiment data
- o Shut down the system.

The command and data processor must interface, on the one hand, with the space station and, on the other hand, with the high voltage power supply experiment hardware. The command and data processor subsystem chosen for the high voltage power supply experiment is a modification of an existing command and data processor subsystem used on three satellites of the P87-2 and nine satellites of the DARPA Lightsat programs. Figure 3.5-1 summarizes its major features and shows a block diagram of the proposed command and data processor.

The command and telemetry requirements are quite complex and extensive, requiring a capable, digital, computer-controlled command and data processor system. This is especially so since it was assumed that the space station cannot provide full-time monitoring of the HVPS test facility.

3.5.1 Space Station and High Voltage Test Facility Interface Considerations.

There are a number of space station and high voltage power supply test facility considerations:

o How much of the command bit stream or command sequence interpretation should be done by the space station versus the high voltage power supply test facility? At one end of the spectrum, the work done by the space station is simply to relay a ground system-prepared bit stream to the high voltage test facility, which must then interpret the command bit stream, partition it into individual commands, operate on these to determine when commands are to be executed, and then prepare the activation of switches, D/A converter or other devices at appropriate times. At the other end of the spectrum, the space station does most of these functions and then transfers the resulting multiple lines to activate experiment-related devices.

o What orbit is the experiment going to be in, where is the ground control system, and how long is the duration over which the HVPS test facility is to store data?

o How much data and telemetry must come down during a pass?

o What is the telemetry and command capability of the space station to support the attached payload experiments?

Due to the large amount of data the space station will be handling, a stored command and stored data collection capability is required. Providing for this capability for the command and data collection capability also provides for data formatting and command bit stream interpretation capability, reducing the requirement on the space station data-bus, without using or requiring any space station computer capabilities.

There are 56 analog measurements to monitor and dump to ground. While the data collection interval is not yet determined, a typical one second sampling interval, assuming 8-bit data samples, would require collecting 448 bits of data per second on just 56 analog measurements. Over 15 minutes this accumulates to 403,200 bits, and allowing for 20% overhead for error detection and correction, 483840 bits must be dumped to ground. At a typical 9600 bps data rate, the collected data from the 56 sensors would take 50.4 seconds (0.84 minutes) to dump to ground. This is a very practical solution.

3.5.2 Command and Data Processor Hardware Functions

The command and data processor performs sensor data collection and conditioning, data management, data storage, telemetry data formatting data bus interface, acceptance and interpretation of the command bit streams and activation of the high voltage test facility. These functions are performed by a digital processor commanded from the ground or space station in high-level, user-oriented language. The processor contains analog and digital inputs, which it multiplexes, A/D converters, scales, operates on, formats and stores. The processor also contains a command decoder for initiating and executing all command functions. In preparing the data for dumping to the space station or the ground, the command and data processor subsystem orders the data for transmission, formats it and reads it out sequentially to the space station data bus.

The digital processor hardware Figure 3.5-2 contains a processor and a memory assembly. The processor hardware is based on the space-qualified 80C86 CPU processor and peripheral modules developed for the STACKSAT (P87-2) program. These modules are packaged on 7.5 in. by 4.5 in PC boards and assembled as a subsystem on a motherboard in an aluminum housing. The photograph in Figure 3.5-2 shows the enclosure as used on P87-2. The enclosed aluminum housing can provide radiation protection for high altitude, long duration missions. The hardware is designed to operate with an 8MHz clock over -40 to +55 degrees C. It is designed for operation at 12G acceleration in each of three axes.

3.5.3 Concepts of operation.

The command and data processor subsystem contains a 75,000 word program to implement the functions listed above. It is controlled from ground or the space station. The commands are prepared by a menu-driven software routine that runs an IBM PC or equivalent.

The functions performed by the computer that the on-board software supports are:

o Initialization of the computer and hardware
o Control of input data-bus
o Management of on-board electric power system (turning power on/off to on-board hardware)
o Monitoring and collecting telemetry status
o Accepting ground and space station commands and interpreting the data
o Collecting, computing and formatting the telemetry
o Storing and retrieving data and messages
o Executing schedules events, housekeeping, communications and telemetry.

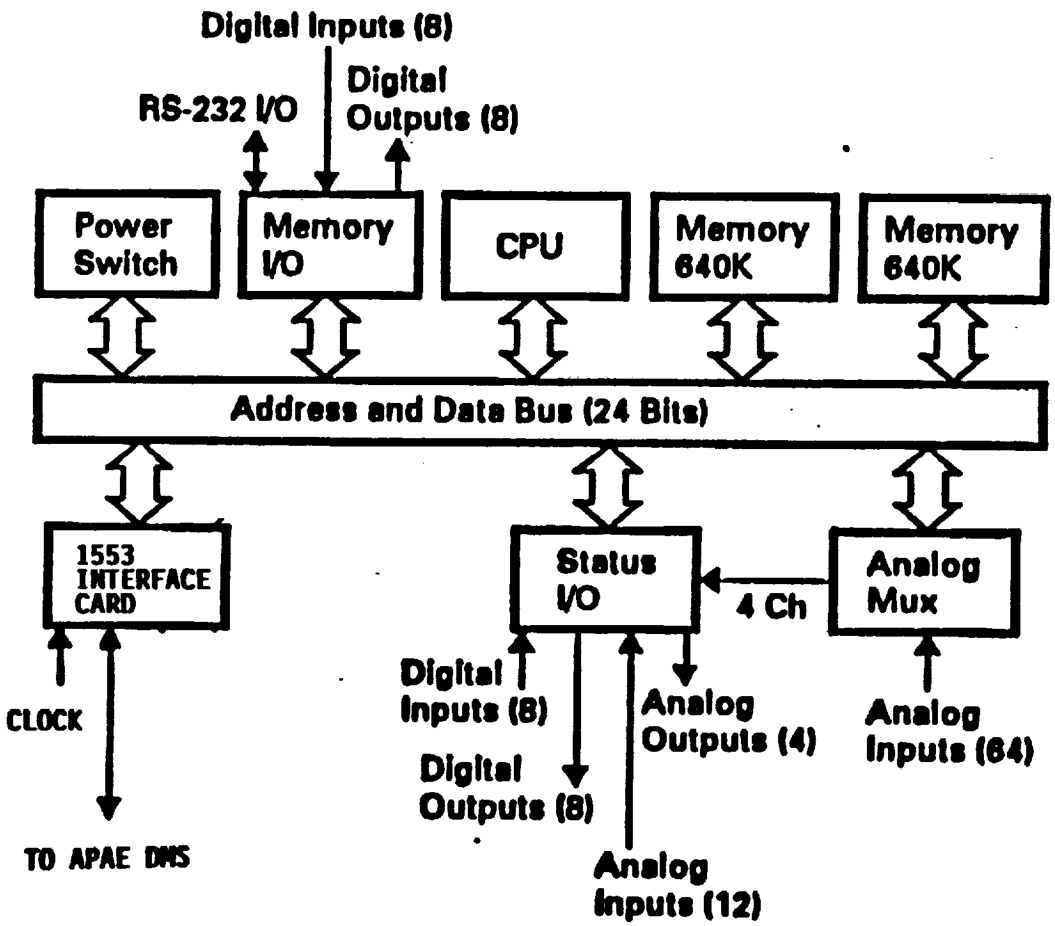
The on-board software contains 70,000 lines of code written in a combination of C and in assembly language for the 80C86 CMOS CPU. It permits the user on the ground or space station to command the experiment functions in high level, user-oriented language from a menu-driven command and control software that runs on an IBM PC and provides the command bit stream to the HVPS test facility during scheduled contacts with the space station central computer. This same software also collects HVPS test facility telemetry dumped the on-board command and data processor.

o Modules and components qualified on P97-2 and Lightsat Satellites

o Provides a single interface for commands and telemetry

o Stores and formats experiment commands and data

A. Features



B. Block Diagram

Figure 3.5-1. mmand and Data Processor Characteristics

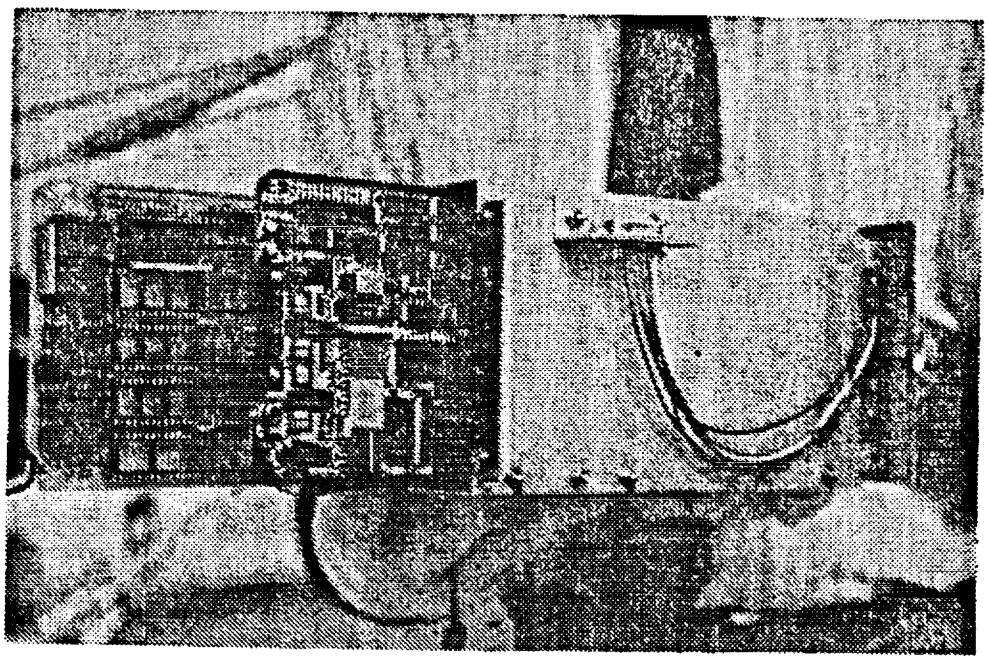


Figure 3.5-2 Command and Data Processor Hardware

4.0 Conclusions

The 60 GHz communication satellite to satellite cross-link technology is an important capability for both NASA/DoD applications where higher data rate and secure communication link is required.

The high voltage power supply test facility program integrates the developed 60 GHz TWT with space vacuum insulated high voltage power supply and provides the accompanying RF communications hardware, high voltage diagnostic package and data management system to demonstrate the 60 GHz cross-link communication system.

The attached payload accommodations equipment interfaces were reviewed and included the following items:

- o Electrical Power System
- o Thermal Control System
- o Space Station Information System for the Data Management System and the Communication and Tracking
- o Environments
- o Contamination Monitoring System
- o Grapple Fixture
- o Mobile Servicing Center
- o Flight Telerobotics Services

A conceptual design of a high voltage power supply test facility was generated which includes a 60 GHz communication experiment and high voltage plasma diagnostic experiment.

An experiment was proposed using the Space Station - freedom and the AXAF satellite with identical equipment onboard each platform.

This experiment will demonstrate the vacuum insulation system for high voltage power supply technology and will demonstrate all of the 60 GHz communication RF technology.

The following follow-on tasks are proposed for future development.

1. Develop 100 kHz parallel resonant dc-dc converter technology for high voltage power supply technology to improve the dc-dc converter efficiency by about 5%.

2. Breadboard a complete 60 GHz communication system to demonstrate technology readiness of the RF communication hardware.

3. Design ,fabricate and test a high voltage power supply test facility as a Space Station flight experiment.

Appendix A

List Of Abbreviations

APAE	Attached Payload Accommodations Equipment
ATCS	Active Thermal Control System
ATDRS	Advanced Tracking Data Relay Satellite
AXAF	Advanced X-ray Astrophysics Facility
BWG	Beam Wave Guide
CCSDS	Consultative Committee for Space Data System
CMD	Command
CMDM	Controller Multiplexer/Demultiplexer
CMS	Contamination Monitoring System
CTS	Communication Technology Satellite
DMS	Data Management System
EPS	Electrical Power System
FTS	Flight Telerobotic Servicer
GHz	Gigahertz
HV	High Voltage
HVPS	High Voltage Power Supply
kV	Kilovolts
MMS	Multi Mission Satellite
MPA	Multiple Payload Adaptor
MSC	Mobile Servicing Center
OMV	Orbital Maneuvering Vehicle
ORU	Orbital Replaceable Unit
PAS	Payload Attachment System
PIA	Payload Interface Adapter
PPS	Payload Pointing System
PTCS	Passive Thermal Control System
SIA	Station Interface Adapter
SSF	Space Station Freedom
SSIS	Space Station Information System
SSMB	Space Station Manned Base
TCS	Thermal Control System
TDRS	Tracking Data Relay Satellite
TLM	Telemetry
TQCM	Temperature Controlled Quartz Crystal Microbalances
TWT	Traveling Wave Tube
TWTA	Traveling Wave Tube Amplifier